Studies Concerning the Elimination of Experimental Error in Comparative Crop Tests

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STUDIES CONCERNING THE ELIMINATION OF EXPERIMENTAL ERROR IN COMPARATIVE CROP TESTS

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CONTENTS

The author wishes to take this opportunity to thank Professors R. J. Pool and W. W. Burr for the interest and advice they have given him in the preparation of this bulletin as a thesis for the degree of Doctor of Philosophy.

SUMMARY

1. In determining the effect of competition between single-row test plats as a source of experimental error in crop yield tests, the relative yields of two crops planted in blocks containing several rows have been regarded as the true relative values for the crops tested. In ascertaining some of these true values, the outer rows of the plats have been discarded in order to eliminate almost entirely plat competition. Plats were sufficiently replicated to secure quite reliable relative yields for the conditions under which they were grown.

In plat competition tests in 1913 with two rates of planting Turkey Red wheat, the thin rate yielded 68 per cent as much as the thick rate when grown in single alternating rows, while in five-row blocks the thin rate yielded 90 per cent as much as the thick rate. Competition in rows with a thicker rate of planting caused the thin rate to yield relatively 24.4 per cent too low. In a similar test in 1914 the thin rate yielded relatively 56.8 per cent too low.

2. In 1913, competition between alternating rows of two rates of planting with Kherson oats caused the thin rate to yield relatively 20 per cent too low. In 1914, similar single-row competition caused the thin rate to yield relatively 34.3 per cent too low.

3. In 1914, competition between alternating single-row plats of Turkey Red wheat sown at two rates reduced the relative number of stools per plant approximately 37 per cent for the thin rate. There was a similar reduction of 20 per cent for Kherson oats, due to plat competition.

4. The relative competitive effect of varieties varies in different years, due to difference in adaptation to the seasonal conditions.

In 1913, competition with Turkey Red winter wheat in single rows caused Big Frame winter wheat to yield relatively 10.3 per cent too high. In similar competition in 1914 Big Frame yielded relatively 12.4 per cent too low.

In 1913 there was practically no competitive effect between alternating rows of Turkey Red and Nebraska No. 28 winter wheat varieties. This was due to abnormal climatic conditions. However, in 1914 under rather normal conditions competition between single-row plats caused the Nebraska No. 28 to yield relatively 25.9 per cent too low.

5. In 1913 in alternating single-row test plats of Burt and Kherson oats, the Burt yielded relatively 16 per cent too high, while in 1914 the yield was relatively 37.6 per cent too high, due to plat competition.

In 1913, competition with Kherson oats in alternating one-row plats caused Swedish Select oats to yield relatively 7 per cent too high, while in 1914 its yield was relatively 4.3 per cent too low.

6. When large and small seeds of wheat were planted in competition in the same row, the small seed, as a result of competition, yielded relatively 15 per cent too little grain, 20 per cent too little straw, and made 18 per cent too small total yield.

Similar competition was found between varieties of wheat planted in the same row.

7. In a single-row test of 80 strains of Turkey Red wheat grown in the same order each of four years, there are evidences of plat competition between strains. As an average for four years, the poorest strain, No. 75, grew between strains No. 74 and No. 76, ranking one and five. A special test of these three strains in 1915 and 1916 disclosed that strains No. 74 and No. 76 were favored 20 and 15 per cent respectively thru competition with a less vigorous strain.

8. In a rate-of-planting test with Nebraska White Prize corn,—in which two rates of planting, namely two and four plants per hill, were compared in alternating single row plats,—the thin rate yielded relatively 29.3 per cent too low in 1914 because of plat competition. In 1915 the thin rate yielded 9 per cent too low because of plat competition. In 1916 such competition caused the thin rate to yield relatively 16.1 per cent too low.

9. A large, medium, and small variety of corn were grown in plat competition studies during 1912 and 1914. These varieties were Hogue's Yellow Dent, University No. 3, and Pride of the North, respectively. In 1912, Pride of the North yielded 85 per cent as much as Hogue's Yellow Dent in alternating three-row plats, while it yielded 66 per cent as much in alternating single rows. When compared in the same hill by the intra-hill method, the Pride of the North yielded only 47 per cent as much as Hogue's Yellow Dent. Due to competition, the Pride of the North yielded relatively 44.7 per cent too low when compared in the same hill, and 22 per cent too low in alternating one-row plats.

10. In 1914, due to plat competition, Pride of the North corn yielded relatively 51 per cent too low when compared with Hogue's Yellow Dent in the same hill, while in alternating single-row plats it yielded relatively 28.3 per cent too low.

In a comparison of University No. 3 with Hogue's Yellow Dent, the University No. 3 yielded relatively eight per cent too low in single-row plats, and within the hill it yielded relatively one per cent too high. The lack of competition within the hill in this case may have been due to there being only two plants of a rather similar type in a hill. When all three varieties were compared in the same hill, the relative yields for Hogue's Yellow Dent, University No. 3, and Pride of the North were respectively 100, 96, and 28, as compared with 100, 98, and 53 in the center row of three-row plats and 100, 98, and 38 in single rows.

11. In 1916, inbred Hogue's Yellow Dent corn which had been greatly reduced in vigor by five years of self-fertilization was compared with the more vigorous first generation hybrid of two such pure lines, in blocks, rows, and hills. Because of competition with the larger plants in the same hill, the inbred corn yielded relatively 44 per cent too low, while in alternating single rows, it yielded relatively 16 per cent too low.

12. Studies with oats, wheat, and corn suggest that the yield of the border rows of narrow, adjacent test plats may be materially affected by plat competition.

13. When surrounded by corn hills having a full stand of three plants, two-plant hills and three-plant hills respectively yielded 10.5 per cent and 35 per cent more than a one-plant hill in 1914. In a similar test in 1917, two-plant hills and three-plant hills respectively yielded 67 and 102 per cent more than a one-plant hill.

14. The average grain yield of a three-plant corn hill surrounded by a full normal stand of three plants per hill was 465.8 grams in 1914. This yield per hill was increased 2.7, 5.3, 13.1, and 43.1 per cent by the presence, respectively, of (1) one adjacent hill with two plants, (2) one adjacent hill with one plant, (3) one adjacent blank hill, and (4) two adjacent blank hills. In 1917 corresponding adjacent imperfect hills increased the grain yield of three-plant hills, otherwise surrounded by a full stand, respectively 2, 9, 15, and 25 per cent.

15. Regarding three plants per hill as a perfect stand, the reduction in yield of corn was not proportional to a reduction in stand. With single-row plats, stands averaging 92.8, 87.2, 82.7, 77.8, 73.1, 66.6, and 43.0 per cent yielded respectively 85.5, 88.1, 83.5, 82.2, 77.9, 74.8, and 56.7 bushels per acre.

16. Satisfactory yield correction for corn based upon per cent of stand cannot be made, because the effect upon yield depends upon the distribution of the missing plants and because the effect upon yield is not proportional to the per cent stand. Comparable yield tests of similar varieties or strains of corn may be secured by basing the yield upon a counted number of hills containing a uniform number of plants and surrounded by a full stand.

17. Corn varieties or types differing markedly in growth characteristics should be tested at several rates of planting, because the optimum rate for one is not necessarily that for another. Thus, as an average for two years, Pride of the North and Calico produced their maximum yield when grown at the rate of five plants per hill, while Mammonth White Pearl yielded best at the three-rate. In 1914, Pride of the North yielded most at the five-rate, University No. 3 did equally well at the two and three-rate, while Hogue's Yellow Dent produced best at the two-rate.

18. The removal of suckers affects the yield of varieties differently, and for this reason suckers should for no reason be removed in comparative variety tests.

19. In comparative yield tests where it is not convenient to harvest and thresh the entire plats, fairly reliable results may be obtained by harvesting and averaging a large number of systematically distributed small fractional areas or quadrates from each plat. The necessary number of quadrates to be representative will vary with the size of the plats.

Twenty 32-inch quadrates harvested from thirtieth-acre wheat plats gave fairly reliable results. Less than 20 proved likely to be unrepresentative of the plats. Very satisfactory results were obtained by having 40 quadrates represent one-fifteenth acre of wheat.

20. Two hundred and seven thirtieth-acre plats were grown to a uniform crop of Kherson oats for the purpose of studying various phases of experimental error. Calculations have been made from them to show: (1) The use and

effectiveness of check plats for reducing test plats to comparable yields; (2) the reduction of error by the replication of plats; (3) the relative reliability of plats of various sizes and shapes; and (4) the significance of the "probable error" as a measure of confidence which may be placed in mean results.

When the odd and even numbered plats of these 207 are regarded as check plats and test plats respectively and the grain yield of each test plat is corrected by the mean of the two adjacent check plats, the coefficient of variability for the actual yields of these test plats is reduced from 7.85 per cent for the actual yields to 7.01 per cent for the corrected yields. Assuming every third plat to be a check, and correcting the intervening plats by the one adjacent check plat, the coefficient of variability was reduced from 7.79 per cent to 7.35 per cent.

With every third plat regarded as a check plat, and the intervening plats corrected progressively by the two nearest checks, the coefficient of variability is reduced from 7.87 to 6.57 per cent. Thus it is seen that none of the three methods of check plat correction have been very effective.

The yield of systematically distributed check plats cannot be regarded as a reliable measure for correcting and establishing correct theoretical or normal yields for the intervening plats.

21. Systematic replication of plats is the most effective and satisfactory means for reducing error caused by soil or other environmental variations. When 200 thirtieth-acre plats were planted to a uniform crop of Kherson oats, the coefficients of variability for the grain yields of single plats and for the mean yields of two, four, and eight plats were 6.30, 4.59, 2.91, and 2.13 per cent respectively. The extreme variation between yields was also reduced from 20.7 bushels for single plats to 7.5 bushels for the means of eight plats.

Reduction of error by averaging adjacent plats (which is equivalent to increasing the size of the plat) was far less effective than systematic replication. The coefficients of variability for single plats and for the mean yields of two, four and eight adjacent plats were 6.30, 5.46, 5.28, and 4.78 per cent.

Variation between long, narrow plats was less marked than for short, wide plats of the same area. The coefficient of variability for tenth-acre oats plats 48 rods by 5.50 feet was

3.84 per cent as compared with 5.18 per cent for plats 16 rods by 16.5 feet.

22. Two hundred uniformly planted thirtieth-acre Kherson oats plats were arranged in 50 groups of four adjacent plats each, and also in 50 groups of four systematically distributed plats. For both methods of grouping, the "probable error" has been calculated for the mean yield of each group of four plats. The results indicate that a small probable error cannot be regarded as sufficient reason for confidence in the reliability of data. Because of chance groupings of either large or small variations where relatively small numbers are used, a mean may be either more or less accurate than an application of the probable error would indicate.

23. In four comparative rate-planting yield tests with small grains in alternating single-row plats the probable error was less than 2 per cent in all cases, and yet there existed an average actual error of 34 per cent in relative yields due to plat competition. Similar results are indicated for variety tests with small grains.

24. An application of the probable error to tests made in 1916 concerning the relative water requirement for grain production of Hogue's Yellow Dent corn and Turkey Red winter wheat may result in greatly misplaced confidence. We may be confident from one test that Hogue's Yellow Dent corn uses considerably less water per pound of grain than does Turkey Red wheat, and from another test we may be equally confident that the corn uses more than twice as much water for grain production as does the wheat. The second comparative figures are unreliable because the soil was relatively overcropped by the corn.

25. Crop tests are subject to such a multitude of local environmental influences that errors in them cannot be regarded as occurring according to the formulas or rules of chance calculated mathematically from purely mechanical observations. The probable error may apply where only accidental variations occur but not where systematic variations exist. Crop tests are subject to systematic variations.

26. In view of the precautions necessary to guard against the invalidating influences of various sources of experimental error, greater and better facilities should be provided experiment stations for the conduct of crop investigations.

27. In crop breeding experiments improvement in yield over the original can only be measured accurately by growing each year some of the original unselected seed for comparison. The method of comparing the results of one period of years with those of another is unreliable. For example, Hogue's Yellow Dent corn which has undergone continuous ear-to-row breeding since 1902 yielded 39 per cent less during the seven-year period 1907-1913 than during the preceding seven years. However, a seven-year comparison with the original seed which has been grown as a check indicates that the inherent yielding power of the ear-to-row and the original corn are almost identical.

28. Soil limitation may be a serious source of error in pot experiments. The relative total moisture-free yields for individual corn plants grown in pots of six sizes in 1914 were, in order from the smallest to the largest, 100, 211, 324.1, 453.6, 643.8, and 747. The corresponding yields of ear corn were 100, 632.5, 1082.3, 2417, 2990, and 4046.7. A uniform application of 1.75 pound of sheep manure per plant (or per pot) increased the yields of total dry matter for the six sizes, in order from the smallest to the largest, 176.4, 95.3, 69.3, 26.1, 12.7, and 7.2 per cent. The corresponding increases in yield of ear corn caused by the manure were 722.5, 193.6, 149.2, 18.9, 14.1, and 2.9 per cent.

In 1915 the relative yields of total dry matter from the six sizes of pots, progressing from the smallest to the largest, were 100, 150, 229.6, 355.6, 586, and 578.7 per cent. The corresponding relative yields of ear corn were 100, 276.2, 819, 1647.5, 2771.3, and 2667.

Applying manure in amounts proportional to the quantity of soil contained, in 1915 had far less striking effect upon the pot yields for the different sizes than when equal quantities were applied in 1914, regardless of the quantity of soil contained.

29. When two, four, or six corn plants were grown in pots of the proper size for growing one normal corn plant, the individual plant yields of total dry matter were respectively 50.8, 26.7, and 16.6 per cent as large as for the one-rate, while the corresponding yields of ear corn were respectively 39.7, 15.9, and 2.8 per cent as large.

30. A review of several hundred experiment station bulletins dealing with variety, fertilizer, cultural, and pot

tests indicates that the statement of methods employed in securing experimental data is often inadequate to acquaint the reader with the manner in which the results were obtained. Such a statement is desirable in order that one may judge regarding the reliability of the results and the degree of confidence which the data merit.

STUDIES CONCERNING THE ELIMINATION OF EXPERIMENTAL ERROR IN COMPARATIVE CROP TESTS

By T. A. KIESSELBACH

It is apparent that many sources of error have unconsciously entered into comparative crop yield tests. The very important matter of overcoming variation in soil conditions as a source of experimental error has been quite extensively studied and reported by various investigators during the past decade. The means suggested for reducing such error have been (1) repetition of plats and (2) correction of yields according to check plats planted to a uniform variety or treatment at stated intervals. Both methods have proved of value and a combination of both may often be used advantageously. Some danger always exists of error occurring in the check plats and that correcting according to them may introduce new errors in the yields of crops compared. The method should, for this reason, be used with caution.

Studies in experimental error conducted at this Experiment Station prior to 1911 have been published by Prof. E. G. Montgomery, now of Cornell University, in Bulletin No. 269, of the Bureau of Plant Industry, U. S. Department of Agriculture, and in the Twenty-sixth Annual Report of the Nebraska Agricultural Experiment Station. These published results concern primarily the general problems of repetition and size of nursery small grain plats, and the use of check plats.

The object of the following investigations was to secure further information regarding the elimination of error in comparative yield tests. Shortage of facilities for carrying on this character of work in addition to the regular crop investigations of the Experiment Station has in some cases necessitated intermittent experiments. The duration of some of the tests has for the same reason been shorter than would have been desired.

Acknowledgment is gratefully made to Professor J. A. Ratcliff and Professor C. A. Helm for valuable assistance in field supervision and in keeping records during much of the time these experiments were in progress. Messrs. H. G. Gould, E. R. Ewing, R. E. Holland and H. B. Pier, have also rendered efficient assistance at various times.

ERROR DUE TO COMPETITION BETWEEN ADJACENT PLATS

It is a well known principle in ecology that a keen competition for soil moisture and nutrients may exist between plants which differ in growth habit, when grown in close proximity. Competition between adjacent rows of different varieties, selections, or rates of planting, had suggested itself as a possible source of error in crop tests. An investigation was planned in 1912 to determine the relative merits of rows and blocks for making comparative yield tests in the small grain nursery and in corn experiments.

The question was: Will two varieties give the same comparative yields when planted in alternating rows as when planted in alternating blocks consisting of a number of rows? It was reasonable to assume that there would be less plat-competition between varieties planted in blocks than when planted in single rows.

It has been a common practice in crop breeding experiments to compare the selected strains in adjacent one-row plats for a number of years. Many other comparative tests have also been made in single row plats.

ILLUSTRATION OF PRINCIPLE OF COMPETITION BETWEEN ADJACENT ROWS

On the right-hand side of Fig. 1 is shown a crop of Turkey Red winter wheat planted in the fall of 1912. To the south of this was planted Scotch Fife spring wheat in the spring of 1913. The first row of spring wheat, spaced ten inches from the winter wheat, is seen to have grown only about four inches tall with no grain production. The second row of spring wheat made an almost normal growth, while the third row was entirely normal. The complete failure of the first row of spring wheat may be accounted for by the shortage of both moisture and available plant food material, due to the more rapid and luxuriant growth of the adjacent winter wheat. While this is an extreme example of competition between adjacent rows, it illustrates a principle commonly applying in crop yield tests.

COMPETITION BETWEEN ADJACENT ROWS OF SMALL GRAIN

The plan of the experiment was to plant two crops under comparison in alternating one-row plats and alternating five-row plats. These were replicated 50 times each year in order

Fig. 1—Illustrating principle of competition between adjacent rows. Winter wheat on right; spring wheat on left. Due to competition with the winter wheat, the first row of spring wheat grew only four inches tall with no grain production. The second row was nearly normal and the third row entirely normal.

to eliminate the accidental mechanical and physical errors due to variation in soil, exposure, stand, etc. These nursery rows were spaced 10 inches apart. The relative yields in either the entire five-row block or the three inner rows, as indicated, were regarded as the correct relative yields for the season. A difference in the relative yields when tested in alternating rows, as compared with the relative yields in blocks, is chiefly due to, and measures, the competition between the crops compared in rows. In part of the tests the blocks were harvested as individual rows, which permitted a study of the effect of plat competition upon the border rows of five-row plats. The straw yields as well as the grain yields were also secured in a portion of the tests.

ROW COMPETITION IN RATE-OF-PLANTING TESTS WITH WHEAT AND OATS

During the years 1913 and 1914, both oats and winter wheat were grown at two distinct rates of planting in both alternating single-row plats and alternating five-row nursery plats, 16 feet in length.

Wheat—Table 1 shows the results with the wheat rate-of-planting tests.

When grown in single rows in 1913, the thin rate yielded 68 per cent as much as the thick rate, while in five-row blocks the thin rate yielded 90 per cent as much as the thick rate. Competition in rows with a thicker rate of planting caused the thin rate to yield relatively 24.4 per cent too low. (This percentage effect of competition is determined by dividing the difference between 68 per cent and 90 per cent, or 22, by 90.)

In 1914 the thin rate in rows yielded 35 per cent as much as the thick rate, while in the center three rows of five-row plats it yielded 81 per cent as much as the thick rate. Due to competition, the thin rate yielded 56.8 per cent too low. If the two outside rows are averaged into the block yield, the

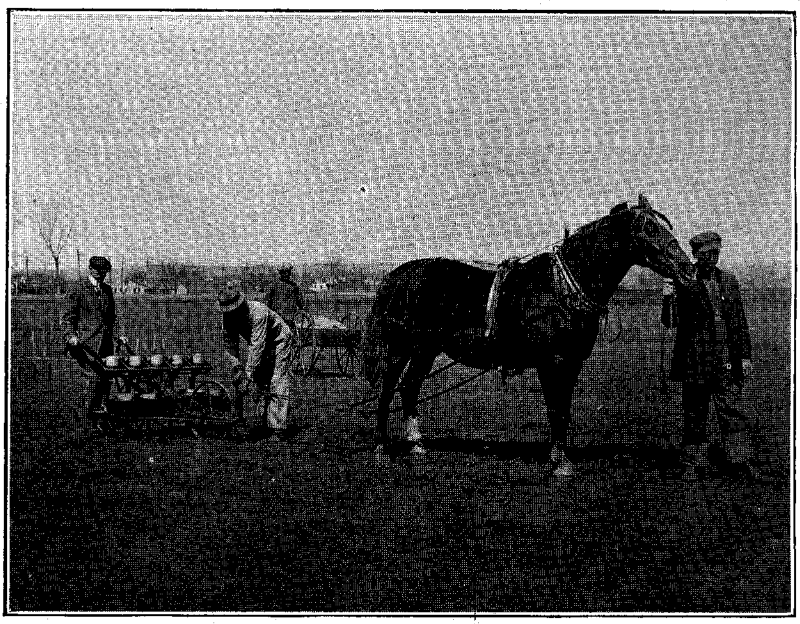


Fig. 2—Method of planting nursery small grain plats with a special nursery drill. The drill can be rapidly adjusted to plant each row at a given rate, independently of the other rows

TABLE 1—*Relative yields of two rates of planting with Turkey Red winter wheat when compared in alternating one-row plats and alternating five-row plats (1913-1914)*

Character of plat	Average yield of grain per row			Average yield of straw per row		
	Thick rate	Thin rate	Ratio thick to thin	Thick rate	Thin rate	Ratio thick to thin
	Grams	*Grams*		*Grams*	*Grams*	
YEAR 1913						
Alternating single-row plats (average of 50 plats)	389 ±5.3*	264 ±3.8	100:68	....	....	......
Alternating five-row blocks (average of 50 plats)	394 ±3.2	355 ±2.8	100:90	....	....	......
YEAR 1914						
Alternating single-row plats (average of 50 plats)	327 ±6.6	115 ±3.6	100:35	1265 ±15.9	494 ±12.2	100:39
Alternating five-row blocks (average of 50 plats)	272 ±4.1	195 ±3.3	100:72	1049 ± 9.5	772 ±7.0	100:74
Two outside rows of block (average of 50 plats)	306 ±5.0	184 ±3.5	100:60	1129 ±11.7	712 ±11.2	100:63
Three inside rows of block (average of 50 plats)	251 ±3.4	203 ±3.6	100:81	994 ± 7.4	812 ±10.0	100:82

*The probable error has been calculated in Tables 1 to 7. For later discussion of the significance of the probable error, see pp. 65-74.

TABLE 2—*Relative yields of two rates of planting with Kherson oats when compared in alternating one-row plats and alternating five-row plats (1913-1914)*

Character of plat	Average yield of grain per row			Average yield of straw per row		
	Thick rate	Thin rate	Ratio thick to thin	Thick rate	Thin rate	Ratio thick to thin
	Grams	*Grams*		*Grams*	*Grams*	
YEAR 1913						
Alternating single-row plats (average of 50 plats)	233 ±4.0	148 ±3.8	100:64	....	....	......
Alternating five row blocks (average of 50 plats)	222 ±2.8	178 ±1.8	100:80	....	....	......
YEAR 1914						
Alternating single-row plats (average of 50 plats)	220 ±3.6	148 ±2.4	100:67	654 ±5.5	451 ±4.8	100:69
Alternating five-row blocks (average of 50 plats)	205 ±2.6	201 ±2.5	100:98	653 ±4.9	659 ±5.0	100:100.9
Two outside rows of block (average of 50 plats)	209 ±2.1	201 ±3.3	100:96	651 ±7.0	644 ±7.6	100:99
Three inside rows of block (average of 50 plats)	202 ±2.0	207 ±2.2	100:102	657 ±3.5	667 ±3.9	100:102

ratio of thick to thin is 100:72 as compared with 100:81 for the center three rows, while the ratio of thick to thin for the two outside rows only was 100:60. From these data and other similar data it may be concluded that the outside rows of nursery test plats should be discarded.

The straw yields for the 1914 rate-of-planting tests with wheat substantiate the same principles of competition as were brought out in the relative grain yields. In alternating rows, the ratio of thick to thin straw yield was 100:39. For the center three rows of five-row blocks, the ratio was 100:82. The ratio was 100:74 where all five rows were averaged, while it was 100:63 for the two outside rows.

Oats—The relative yields of two rates of planting oats in alternating rows as compared with alternating five-row plats are shown in Table 2. In 1913 the thin rate in rows yielded 64 per cent as much as the thick rate, while in five-row blocks the thin rate yielded 80 per cent as much as the thick rate. Competition in rows with a thicker rate of planting caused the thin rate to yield relatively 20 per cent too low.

In 1914 the thin rate in alternating rows yielded 67 per cent as much as the thick rate, while when compared in the three inner rows of five-row plats the thin rate yielded 2 per cent more than the thick rate. Competition in rows with the thicker rate caused the thin rate of planting to yield relatively 34.3 per cent too low. If the yields of the entire five-row blocks are taken, the ratio of thick to thin is found to have been 100:98 as compared with 100:102 for the three inside rows, while the ratios of thick to thin for the two outside rows was 100:96.

Similar results were obtained from the straw yields in 1914. In alternating single rows the ratio of thick to thin straw yields was 100:69. For the center three rows of five-row blocks the ratio was 100:102. Where all five rows were averaged the ratio was 100:101, while for the two outside rows it was 100:99.

RELATIVE STOOLING OF TWO RATES OF PLANTING WHEN COMPARED IN ALTERNATING ROWS AND ALTERNATING BLOCKS

In 1914, counts were made to determine the effect of competition between alternating rows of two rates of planting wheat and oats upon the relative stooling in the two rates. The counts were made for the plats reported in Tables 1 and 2. The results are given in Table 3.

TABLE 3—*Relative stooling of two rates of planting with Turkey Red Wheat and Kherson oats when compared in alternating one-row plats and alternating five-row plats (1914).*

Character of plats and rate of planting	No. plants in 10 feet of row	No. stools in 10 feet of row	No. stools per plant
WHEAT 1914			
One-row plats			
Thick rate	140	620	4.4
Thin rate	52.5	281	5.4
Ratio thick to thin	100:37	100:45	100:123
Five-row plats (middle 3 rows)			
Thick rate	150	560	3.7
Thin rate	50.5	364	7.2
Ratio thick to thin	100:34	100:65	100:195
OATS 1914			
One-row plats			
Thick rate	195.5	392.5	2.0
Thin rate	100.5	271.0	2.7
Ratio thick to thin	100:51	100:69	100:135
Five-row plats (middle 3 rows)			
Thick rate	195	380	1.9
Thin rate	100	320	3.2
Ratio thick to thin	100:51	100:84	100:168

In the alternating rows of wheat, the actual number of plants per row were in the ratio of 100:37, while in the three inside rows of the five row plats the ratio was 100:34. The number of culms per plant in the alternating thick and thin rows were in the ratio of 100:123, while in the center three rows of the five row plats the ratio was 100:195.

In the case of the oats, the actual number of plants per row were in the ratio of 100:51, both for the alternating rows and for the three inside rows of the five-row blocks. The number of culms per plant in the alternating thick and thin rows were in the ratio of 100:135, while for the center three rows of the five-row plats the ratio was 100:168.

ROW COMPETITION BETWEEN VARIETIES OF WHEAT AND OATS

Wheat—During the years 1913 and 1914, Big Frame winter wheat was compared with Turkey Red winter wheat in both alternating single-row plats and alternating five-row

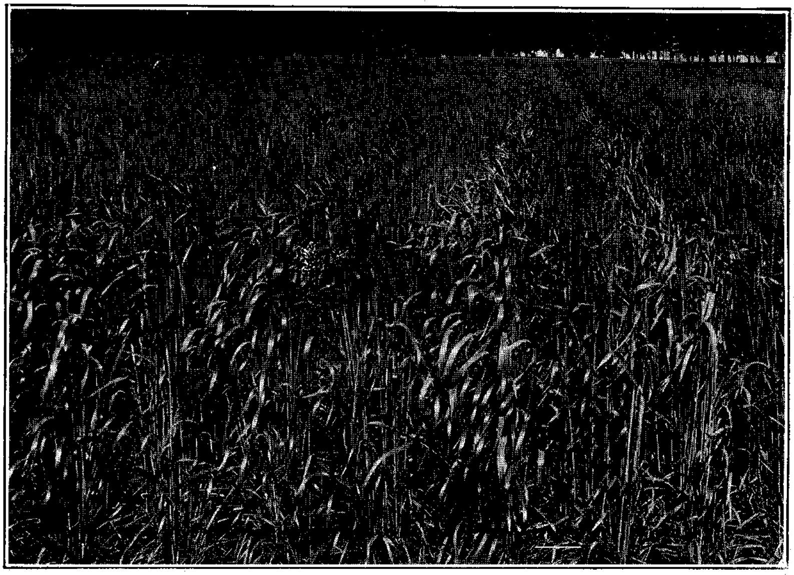


Fig. 3—Competition between two types of wheat in adjacent rows. The single-row method of testing is unreliable

Fig. 4—The "block" method of comparing varieties or selections for yield in the nursery. The two outside rows of each block should be discarded in order to avoid error from competition between adjacent plats. Part of the plats have been harvested

plats. A similar comparison was also made between Turkey Red and Nebraska No. 28 winter wheat.

Turkey Red is the standard bearded hard winter variety for normal Nebraska conditions, while Big Frame is one of the best beardless varieties of rather similar growth habits. The Nebraska No. 28 is an early wheat ripening about ten days before Turkey Red, and is normally six inches shorter. The relative growths of these varieties differ somewhat in different years according to their response to varying climatic conditions. This will account for one variety outyielding in one season, and another variety in a different season. For example, in 1913 the Nebraska No. 28 wheat grew fully as tall as Turkey Red, because it had attained its maximum height before dry weather set in, which somewhat stunted the more slowly developing Turkey Red wheat. The season of 1914 was more favorable for the Turkey Red wheat, which produced a normal, relatively greater vegetative growth.

Table 4 gives the two years' results with Turkey Red and Big Frame wheat. When grown in alternating single rows in 1913, the Big Frame yielded 7 per cent more grain than the Turkey Red wheat, while in alternating five-row plats, the Big Frame yielded 3 per cent less than the Turkey Red. Due to competition, the Big Frame yielded relatively 10.3 per cent too high in single-row plats.

In 1914, the Big Frame yielded 85 per cent as much grain as Turkey Red when compared in alternating one-row plats, while it yielded 97 per cent as much in five-row plats. Competition in rows with Turkey Red caused the Big Frame to yield relatively 12.4 per cent too low.

The straw yields for 1914 give results similar to those for grain. In alternating rows the ratio of Turkey Red to Big Frame straw yields was 100:90. In five-row plats this ratio was 100:97.

Table 5 gives the relative yields of Turkey Red and Nebraska No. 28 wheat during 1913 and 1914. The ratio of Turkey Red to Nebraska No. 28 grain yield was 100:107 in 1913, both when grown in alternating single-row plats and alternating five-row plats. The growth of the two varieties this year was so similar that competition appears to have been a negligible factor.

In 1914 the Nebraska No. 28 yielded 63 per cent as much as the Turkey Red when compared in alternating single-row plats, while it yielded 85 per cent as much in alternating

TABLE 4—*Relative yields of Turkey Red and Big Frame wheat when compared in alternating one-row plats and alternating five-row plats (1913-1914)*

Character of plat	Average yield of grain per row			Average yield of straw per row		
	Turkey Red	Big Frame	Ratio Turkey Red to Big Frame	Turkey Red	Big Frame	Ratio Turkey Red to Big Frame
	Grams	*Grams*		*Grams*	*Grams*	
YEAR 1913						
Alternating single-row plats (average of 50 plats).......	325 ±4.4	347 ±4.0	100:107	....	....	......
Alternating five-row blocks (average of 50 plats)........	408 ±2.6	397 ±2.9	100:97	....	....	......
YEAR 1914						
Alternating single-row plats (average of 50 plats).......	342 ±3.1	290 ±3.6	100:85	981 ±8.2	881 ±6.1	100:90
Alternating five-row blocks (average of 50 plats).......	320 ±3.7	310 ±4.0	100:97	993 ±7.7	963 ±7.9	100:97

TABLE 5—*Relative yields of Turkey Red and "Nebraska No. 28" wheat when compared in alternating one-row plats and alternating five-row plats (1913-1914)*

Character of plat	Average yield of grain per row			Average yield of straw per row		
	Turkey Red	Nebraska No. 28	Ratio Turkey Red to Nebraska No. 28	Turkey Red	Nebraska No. 28	Ratio Turkey Red to Nebraska No. 28
	Grams	*Grams*		*Grams*	*Grams*	
YEAR 1913						
Alternating single-row plats (average of 50 plats).......	365 ±3.9	390 ±3.2	100:107	....	....	......
Alternating five-row plats (average of 50 plats).........	396 ±3.3	423 ±2.8	100:107	....	....	......
YEAR 1914						
Alternating single-row plats (average of 50 plats).......	369 ±4.3	232 ±2.7	100:63	1258 ±8.7	669 ±5.6	100:53
Alternating five-row blocks (average of 50 plats).......	334 ±4.7	285 ±3.6	100:85	1088 ±8.0	875 ±8.0	100:80
Two outside rows of blocks (average of 50 plats).....	....	253 ±3.9	......	....	785 ±7.8	......
Three inside rows of blocks (average of 50 plats).....	....	307 ±3.1	......	....	935 ±5.9	......

five-row plats. In rows competition caused the Nebraska No. 28 to yield relatively 25.9 per cent too low. In this test the Nebraska No. 28 five-row plats were harvested as separate rows. The center three rows, free from competition with the ranker growing Turkey Red variety, yielded 21.0 per cent more per row than did the two outside rows. The three inside rows also yielded 7.7 per cent more per row than did the entire five-row plat.

The straw yields for 1914 indicate similar effect of competition. Compared in alternating single-row plats, the ratio of Turkey Red to Nebraska No. 28 straw yields was 100:53, while in five-row plats this ratio was 100:80. The center three rows yielded 19.1 per cent more straw per row than did the two outer rows, which were obliged to compete with Turkey Red. The center three rows also yielded relatively 6.9 per cent more straw per row than did the entire five-row plat with the two outside rows included.

Oats—Both Burt and Swedish Select oats varieties were compared during 1913 and 1914 with Kherson oats in alternating single-row and alternating five-row plats.

Kherson oats is the standard early variety grown at the Nebraska Experiment Station. Burt oats is rather similar in growth habit to the Kherson, ripening at about the same time. The Swedish Select is a somewhat taller variety, ripening about ten days later.

Table 6 gives the two years' results with Kherson and Burt oats. In 1913 the Burt outyielded the Kherson 30 per cent when planted in alternating single rows and 12 per cent in alternating five-row plats. Due to competition the Burt yielded relatively 16 per cent too high in single-row plats.

In 1914 the Burt yielded 39 per cent more than the Kherson in alternating single row plats, while it yielded 1 per cent more in the three center rows of alternating five-row plats. Competition in rows with Kherson oats caused the Burt to yield relatively 37.6 per cent too high. If the yields of the entire five-row plats are taken, the ratio of Kherson to Burt oats is 100:109 as compared with 100:101 for the three inside rows, and 100:120 for the two outside rows.

The straw yields which were obtained for 1914 gave very similar results. In alternating single rows the ratio of Kherson to Burt straw yields was 100:139. For the three inside rows of alternating five-row plats the ratio was 100:109. For the entire five-row plats the ratio was 100:117. For the two outside rows it was 100:129.

TABLE 6—*Relative yields of Kherson and Burt oats when compared in alternating one-row plats and alternating five-row plats (1913-1914)*

Character of plat	Average yield of grain per row			Average yield of straw per row		
	Kherson oats	Burt oats	Ratio Kherson to Burt	Kherson oats	Burt oats	Ratio Kherson to Burt
	Grams	*Grams*		*Grams*	*Grams*	
YEAR 1913						
Alternating single-row plats (average of 50 plats).......	201 ±3.6	261 ±3.9	100:130	....	....	......
Alternating five-row blocks (average of 50 plats).......	209 ±1.9	234 ±1.9	100:112	....	....	......
YEAR 1914						
Alternating single-row plats (average of 50 plats).......	152 ±2.3	211 ±3.4	100:139	486 ±7.6	676 ±7.4	100:139
Alternating five-row blocks (average of 50 plats)........	193 ±2.3	210 ±2.4	100:109	663 ±3.8	773 ±3.9	100:117
Two outside rows of blocks (average of 50 plats).....	178 ±3.3	214 ±2.5	100:120	615 ±6.4	793 ±5.3	100:129
Three inside rows of blocks (average of 50 plats).....	204 ±2.2	207 ±2.2	100:101	696 ±3.7	760 ±3.3	100:109

TABLE 7—*Relative yields of Kherson and Swedish Select oats when compared in alternating one-row plats and alternating five-row plats (1913-1914)*

Character of plat	Average yield of grain per row			Average yield of straw per row		
	Kherson	Swedish Select	Ratio Kherson to Swedish Select	Kherson	Swedish Select	Ratio Kherson to Swedish Select
	Grams	*Grams*		*Grams*	*Grams*	
YEAR 1913						
Alternating single-row plats (average of 50 plats).......	192 ±2.6	157 ±2.5	100:82	....	....	......
Alternating five-row blocks (average of 50 plats)........	191 ±1.9	147 ±1.8	100:77	....	....	......
YEAR 1914						
Alternating single-row plats (average of 50 plats).......	205 ±3.3	182 ±2.5	100:89	620 ±5.2	698 ±4.8	100:113
Alternating five-row blocks (average of 50 plats)........	219 ±2.4	204 ±2.6	100:93	662 ±3.3	744 ±5.2	100:117

Table 7 summarizes the two years' data with Kherson and Swedish Select oats. In 1913 the Swedish Select yielded 18 per cent less than the Kherson when grown in alternating single-row plats, and 23 per cent less in alternating five-row plats. In alternating single rows the Swedish Select yielded relatively 7 per cent too high.

In 1914 the Swedish Select yielded 89 per cent as much grain as Kherson in alternating single-row plats and 93 per cent as much in five-row plats. The Swedish Select straw yielded 13 per cent more in alternating rows and 17 per cent more in five-row plats.

EVIDENCE OF PLAT COMPETITION IN A WHEAT-BREEDING NURSERY

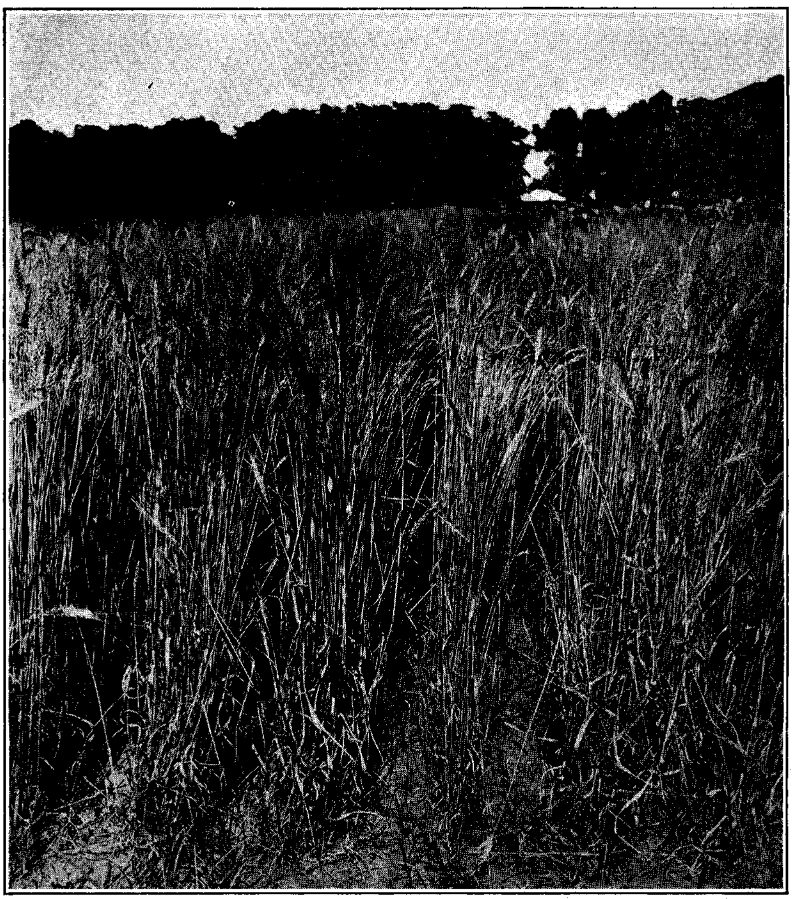
During the four years, 1910, 1911, 1912 and 1914, 80 strains of Turkey Red wheat were tested at the ordinary field rate of seeding in identically the same order each year, in single 16-foot rows ten inches apart. The entire series has been replicated ten times each year. It is probable that many of the yields have been subject to the effect of row competition.

Table 8 contains a concrete example of competition between strains in such a wheat-breeding nursery. In the four-year row test of 80 strains, strain No. 75 ranked 80, while strains No. 74 and No. 76 on either side ranked 1 and 5. Strain No. 75 is a slightly shorter and thinner stooling type. To determine whether the relative rankings of these strains might have been influenced by competition, they were compared in both rows and blocks for two years, 1915-1916.

TABLE 8—*Relative yields of three Turkey Red wheat strains when compared in five-row nursery plats and in single-row plats. Two-year average (1915-1916)*

Strain number	Relative yields	
	Blocks	Rows
GRAIN		
74	106	126
75	100	100
76	108	123
STRAW		
74	110	113
75	100	100
76	102	109

Strain No. 74 was favored 20 per cent and strain No. 76, 15 per cent in yield by being compared (with an adjacent less vigorous type) in rows rather than in blocks. Fig. 5 is a photograph of these strains.



Strain No.: Ck. 74 75 76

Fig. 5—Single-row nursery test plats of Turkey Red Winter wheat. Strain No. 75, in center, is seen to have a lower stooling capacity and is given and unfair test when growing between two high-stooling strains. The two adjacent strains in turn have an unfair advantage

These 80 strains are now all being grown in five-row plats, replicated ten times, for the purpose of establishing the correct relative yields, free from competition as a source of experimental error. Single-row plats are now regarded as unreliable and misleading, because a strain is certain to be unduly favored when grown beside a strain lower in competitive qualities due to such factors as low stooling, slow growing, or partial winterkilling. It is important to have any crop being tested surrounded by a crop of its own kind.

COMPETITION BETWEEN INDIVIDUAL PLANTS

Altho the yields of small grain are never compared by planting alternating seeds of two varieties or two grades of seed in the same row, yet such a comparison may be of interest to throw further light upon the principle of competition.

TABLE 9—*Relative yields, at the normal field rate of planting, of equal numbers of large and small wheat seeds when grown alone in blocks and when grown in competition by alternation in the same row**

Method of comparing large and small seeds	Ratio of yield of small seeds to large seeds		
	Grain	Straw	Total
WINTER WHEAT, 1914			
Grades alone in blocks	90:100	94:100	94:100
Grades competing	61:100	72:100	71:100
WINTER WHEAT, 1915			
Grades alone in blocks	99:100	98:100	98:100
Grades competing	83:100	78:100	79:100
SPRING WHEAT, 1914			
Grades alone in blocks	88:100	93:100	92:100
Grades competing	78:100	78:100	78:100
SPRING WHEAT, 1915			
Grades alone in blocks	80:100	93:100	90:100
Grades competing	82:100	73:100	75:100
AVERAGE FOR WINTER AND SPRING WHEAT, 1914-1915			
Grades alone in blocks	89:100	94:100	93:100
Grades competing	76:100	75:100	76:100

*Compiled from data in Nebraska Research Bulletin No. 11, 1917.

During 1914 and 1915 large and small wheat seeds were planted alternatingly in the row at the normal field rate of planting. Two varieties were used and reciprocated so that the results in Table 9 represent the mean of two varieties for each grade. This reciprocation eliminates largely the varietal effects in the summary. It was necessary to use two distinct varieties (a bearded and a beardless) so that the plants from each grade might be separated at harvest. The same grades were also compared separately in nursery blocks to establish the relative yields when free from competition.

As an average for two varieties each of winter and spring wheat for two years, the small seed in competition yielded relatively 15 per cent too little grain, 20 per cent too little straw, and made 18 per cent too small total yield.

TABLE 10—*Relative yields at the normal field rate of planting, of two varieties when grown alone in blocks, and when grown in competition by alternation in the same row**

Method of comparing varieties		Relative yields		
		Grain	Straw	Total
WINTER WHEAT, 1914				
Ratio Big Frame to Turkey Red	Alone	90:100	88:100	89:100
	Competition	55:100	70:100	67:100
SPRING WHEAT, 1914				
Ratio Scotch Fife to Marquis	Alone	75:100	93·100	90:100
	Competition	61:100	90:100	86:100
WINTER WHEAT, 1915				
Ratio Big Frame to Turkey Red	Alone	82:100	105:100	99:100
	Competition	120:100	128:100	125:100
SPRING WHEAT, 1915				
Ratio Scotch Fife to Marquis	Alone	95:100	114:100	109:100
	Competition	99:100	125:100	119:100

*Compiled from data in Nebraska Research Bulletin No. 11, 1917.

The results for different years should not be averaged in this variety test, since varieties do not have the same relative competitive qualities in different years. We are interested here in what may happen any one year and not in an average of years.

In similar manner, competition between two varieties planted within the same row was determined. Plants from each variety could be separated at harvest by the presence or absence of beards. The relative yields were also obtained in nursery blocks free from competition by harvesting the three inside rows of five-row blocks. The results in Table 10 indicate marked competition between varieties. Variety competition amounted to 61 per cent and 46 per cent for winter wheat yields in 1914 and 1915 respectively. For spring wheat this competition equaled 19 per cent and 4 per cent in 1914 and 1915 respectively.

COMPETITION BETWEEN CORN TEST PLATS AS A SOURCE OF EXPERIMENTAL ERROR

In corn variety tests, corn breeding experiments, and various other corn yield tests the crops under comparison have customarily been planted in adjacent plats containing one, two, three, or four rows. The single-row plat is used almost universally in corn breeding experiments. In several instances where only three or four kinds of corn were to be compared, these have all been planted in the same hill, giving each kind of corn a definite position in the hill. This intra-hill method has been employed by Hartley, Brown, Kyle, and Zook (1912) and by Collins (1914).*

Fig. 6—Planting experimental corn plats where accuracy is required. Hand planters are found far superior to planting with a hoe. A stated number of kernels are placed in the planter for each drop

*The year in parentheses following an author's name in the text serves to associate the reference with a particular publication in the Bibliography (pp. 91-94), where the complete title is given.

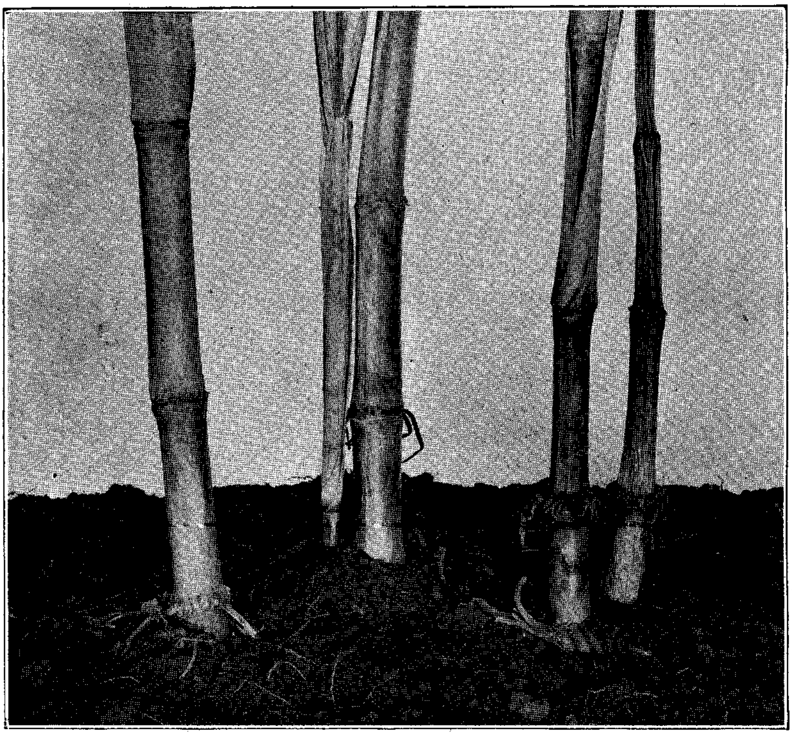


Fig. 7—A hill of checked corn with the three plants spaced in the hill in order that the plants may be readily counted without suckers being mistaken for separate plants

In 1912 the Nebraska Experiment Station commenced a series of experiments to determine the reliability of the various kinds of corn test plats. The investigations were extended in 1913 but the corn was not harvested because of an almost total crop failure due to deficient rainfall. Good results were secured in 1914, 1915, and 1916.

For planting, the land was marked off into hills three feet, eight inches apart and the corn planted at double the desired rate by means of hand planters. (Fig. 6.) When about four inches high the plants were thinned to the desired rate, thus producing an almost perfect stand. The plants were spaced within the hills so that the original plants could be easily distinguished from suckers. For the comparative yield tests, 50 hills with the desired number of plants and surrounded by a normal stand were harvested from each row. This was accomplished by planting 72 hills in each row, which permitted the elimination of any hills having less than the full stand. Thus all yields were comparable so far as number of plants was concerned. The plats have been replicated eight or more times each year, as indicated in the tables, in order to eliminate soil variations.

ROW COMPETITION IN RATE-OF-PLANTING TESTS WITH CORN

Tables 11, 12, and 13 contain three years' results with planting Nebraska White Prize corn at the rate of two and four plants per hill in alternating single-row and three-row

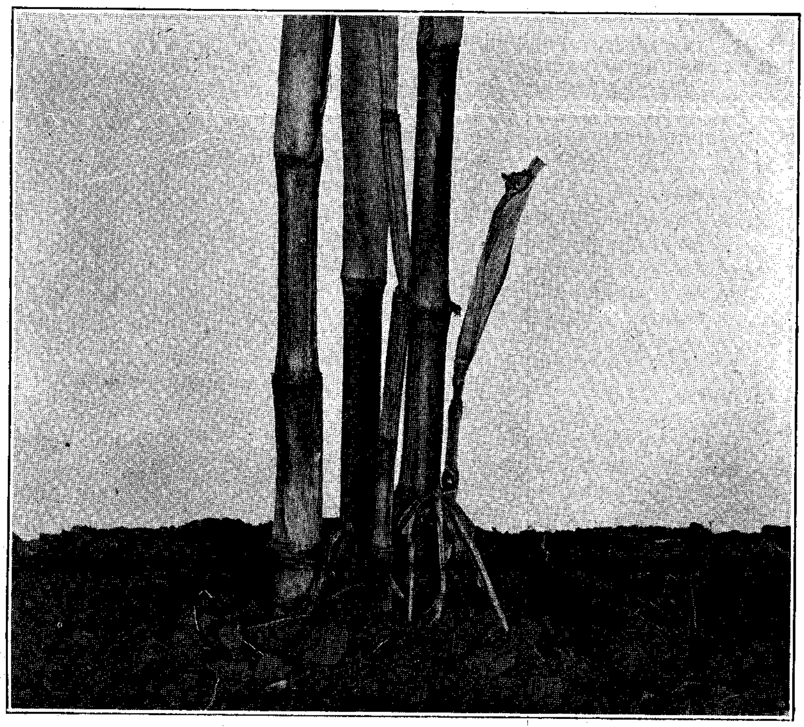


Fig. 8—A hill of checked corn planted by the ordinary method without spacing the plants in the hill. It contains two plants, altho the number cannot be readily nor accurately determined as with the space-planted hill

TABLE 11—*Relative yields of two rates of planting with Nebraska White Prize corn when compared in alternating one-row plats and in alternating three-row plats (1914)*

No. of rows in plat	No. of plants per hill	No. of replications	No. of suckers per 100 plants	No. of ears per 100 plants	Yield per acre: One-row plat or center row		Yield per acre: Average of two outside rows
					Bushels	*Per cent*	*Bushels*
1	4	15	7.4	67.0	43.8	100.0	....
1	2	15	26.6	93.0	35.6	82.0	....
3	4	9	7.1	66.0	38.4	100.0	39.8
3	2	9	32.3	96.0	44.3	116.0	42.4

plats. The rows were harvested separately in the three-row plats.

In 1914 the two-rate yielded 18 per cent less than the four-rate when compared in alternating single-row plats. In the center rows of alternating three-row plats, the two-rate yielded 16 per cent more than the four-rate. Due to competition with a thicker stand, the two-rate yielded relatively 29.3 per cent too low in alternating single-row plats. In the two outer rows of the three-row plats, the ratio of the four-rate to the two-rate was 100:106.5 as compared with 100:116 for the center rows.

TABLE 12—*Relative yields of two rates of planting with Nebraska White Prize corn when compared in alternating one-row plats and alternating three-row plats (1915)*

No. of rows in plat	No. of plants per hill	No. of replications	No. of suckers per 100 plants	No. of ears per 100 plants	Yield per acre: One-row plat or center row		Yield per acre: Average of two outside rows
					Bushels	*Per cent*	*Bushels*
1	4	8	8.5	95	101.7	100.0	....
1	2	8	21.8	110	64.2	63.1	....
3	4	8	11.9	93	90.0	100.0	91.2
3	2	8	29.7	112	62.0	70.0	63.0

In 1915 (Table 12), the two-rate yielded 36.9 per cent less than the four-rate when compared in alternating single-row plats. In the center rows of alternating three-row plats the two-rate yielded 30 per cent less than the four-rate. Due to competition, the two-rate yielded relatively 9.9 per cent too low in single-row plats. In the two outer rows the ratio of the four-rate to the two-rate was 100:69 as compared with 100:70 for the center rows. Competition was far less marked in 1915 than in 1914 because of much more favorable moisture conditions.

In 1916 (Table 13), the two-rate yielded 21.3 per cent less than the four-rate when compared in alternating single-row plats. In the center rows of alternating three-row plats the two-rate yielded 6.2 per cent less than the four-rate. As the result of competition, the two-rate yielded relatively 16.1 per cent too low in single row plats. In the two outer rows the ratio of the four-rate to the two-rate was 100:85.9 as compared with 100:93.8 for the center rows.

TABLE 13—*Relative yields of two rates of planting with Nebraska White Prize corn when compared in alternating one-row plats and alternating three-row plats (1916)*

No. of rows in plat	No. of plants per hill	No. of replications	No. of suckers per 100 plants	No. of ears per 100 plants	Yield per acre: One-row plat or center row		Yield per acre: Average of two outside rows
					Bushels	*Per cent*	*Bushels*
1	4	8	24.8	82	52.7	100	....
1	2	8	62.5	107.1	41.5	78.7	....
3	4	8	23.0	79.9	51.8	100	53.4
3	2	8	60.0	115.6	48.6	93.8	45.9

INTRA-HILL AND ROW COMPETITION IN CORN VARIETY YIELD TESTS

During the years 1912 and 1914, Pride of the North corn was compared with Hogue's Yellow Dent corn in (1) alternating single rows, (2) alternating three-row plats, and (3) in the same hill. A similar comparison was also made between University No. 3 corn and Hogue's Yellow Dent in 1914. The relative yields of the above three varieties were also determined by planting all in the same hill.

The relative growth habits of these three varieties during 1914 is shown in Table 14. Hogue's Yellow Dent is a large variety of corn requiring the entire season to mature. Pride of the North is a small, early-maturing variety. University No. 3 is normally somewhat earlier and smaller than Hogue's Yellow Dent.

TABLE 14—*Relative growth characters of three corn varieties used in 1914 (Table 16) to determine the amount of error from variety competition when tested by the single-row and intra-hill methods (1914)*

Variety	Length of growing season	Height of stalk	Leaf-area per plant
	Days	*Inches*	*Sq. In.*
Hogue's Yellow Dent	119	96	997
University No. 3	107	92	940
Pride of the North	92	70	408

Fig. 9—Alternating single-row plats of Hogue's Yellow Dent and Pride of the North corn, 1914. The row method of testing corn types which differ in growth habit is unreliable because of competition between the plats

Fig. 10—Alternating three-row plats of Hogue's Yellow Dent and Pride of the North corn, 1914. Pride of the North on the right. Competition between test plats may be avoided and correct relative yields obtained by discarding the outside rows of three-row plats

In 1912 Hogue's Yellow Dent and Pride of the North corn were grown in alternating single rows and in alternating three-row plats at the rate of three plants per hill in each case. These were also compared for yield by growing one plant of each variety in the same hill. For this reason the variety yields per acre in the hill method are on a different basis than in case of the rows and blocks, but nevertheless they are comparable. The three-row plat tests were replicated 10 times, the single row plats 20 times, and the hills 1,000 times. The results are contained in Table 15.

In alternating three-row plats, Pride of the North yielded 85 per cent as much as Hogue's Yellow Dent, while in alternating single-row plats it yielded 66 per cent as much as the Hogue's Yellow Dent. Within the same hill, Pride of the North yielded 47 per cent as much as Hogue's Yellow Dent. Due to competition Pride of the North yielded relatively 44.7 per cent too low in the same hill, and 22.4 per cent too low in the alternating rows.

In 1914 Hogue's Yellow Dent corn was compared with University No. 3 corn in addition to a comparison with Pride of the North as made in 1912. All three varieties were also compared in the same hill. Plats were replicated the same as in 1912. The results are contained in Table 16.

In the center row of alternating three-row plats, Pride of the North yielded 53 per cent as much as Hogue's Yellow Dent, while in alternating single row plats it yielded 38 per cent as much as Hogue's Yellow Dent. Within the same

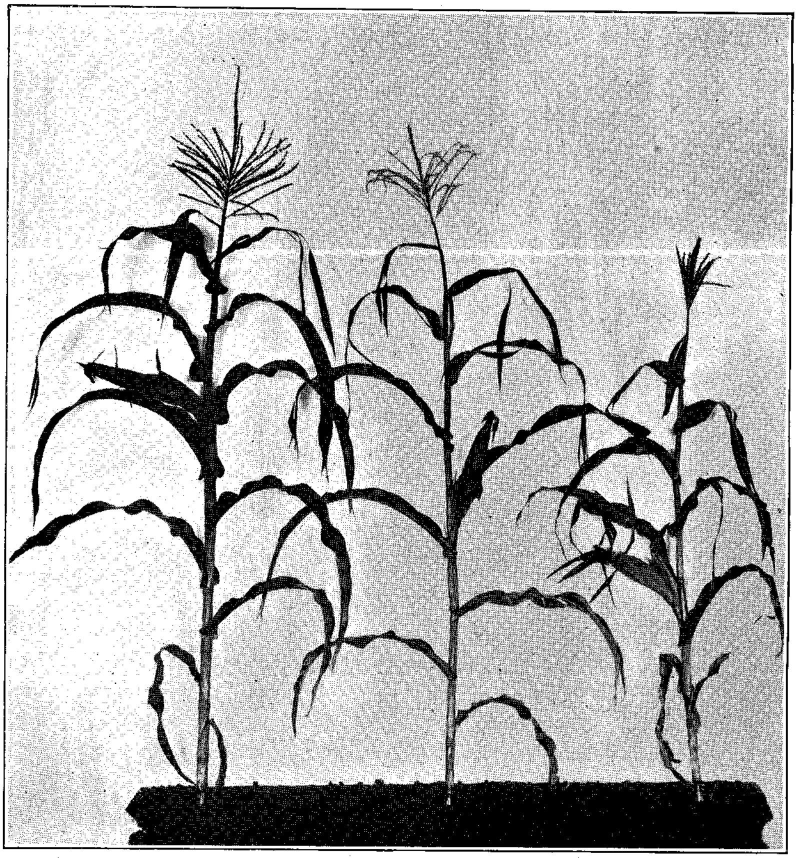


Fig. 11—Relative growth of Hogue's Yellow Dent, University No. 3, and Pride of the North corn varieties when grown in the center row of three-row plats (1914)

hill, Pride of the North yielded 26 per cent as much as Hogue's Yellow Dent. Due to competition with Hogue's Yellow Dent in the same hill, Pride of the North yielded relatively 51 per cent too low, while in alternating single-row plats it yielded relatively 28.3 per cent too low.

Comparing the yields of Hogue's Yellow Dent and University No. 3 in the center rows of alternating three-row plats we have a ratio of 100:98, while in alternating single-row plats this ratio was 100:90. In the same hill the ratio

Fig. 12—Relative growth of Hogue's Yellow Dent, University No. 3, and Pride of the North corn varieties when grown in the same hill (1914)

TABLE 15—*Relative yields of corn varieties differing in growth habits, when compared in three-row plats, single-row plats, and when planted in the same hill (1912)*

Varieties* compared and manner of planting	Plants per hill	No. of replications	Yield per acre: Actual: Hogue's Yellow Dent	Yield per acre: Actual: Pride of the North	Yield per acre: Relative: Hogue's Yellow Dent	Yield per acre: Relative: Pride of the North
			Bushels	*Bushels*	*Per cent*	*Per cent*
Hogue's Yellow Dent and Pride of the North alternating in three-row plats	3	10	38.4	32.9	100	85
Hogue's Yellow Dent and Pride of the North alternating in single rows	3	20	50.8	33.7	100	66
Hogue's Yellow Dent and Pride of the North planted in the same hill†	2	1000	26.2	12.2	100	47

*Hogue's Yellow Dent is a standard, large, later-maturing variety of corn, while the Pride of the North used in this test was medium small with a 16-day shorter growth period.

†Where one plant of each of two varieties was grown in the same hill, the actual yield for each variety is given—based on the rate of one plant per hill.

TABLE 16—*Relative yields of corn varieties, differing in growth habits, when compared in three-row plats, single-row plats, and when planted in the same hill (1914)*

Varieties Compared	Three-row blocks: Plants per hill	Three-row blocks: No. of replications	Three-row blocks: Yield per acre: Center row		Three-row blocks: Yield per acre: Two outside rows	Adjacent Single rows: Plants per hill	Adjacent Single rows: No. of replications	Adjacent Single rows: Yield per acre		Planted in same hill: Plants of each variety per hill	Planted in same hill: No. of replications	Planted in same hill: Yield per acre*	
		Plats	*Bus.*	*Per ct.*	*Bus.*		*Plats*	*Bus.*	*Per ct.*		*Hills*	*Bus.*	*Per ct.*
Hogue's Yellow Dent	3	10	63.1	100	68.4	3	20	77.8	100	1	1000	36.9	100
and													
Pride of the North	3	10	33.7	53	29.1	3	20	29.2	38	1	1000	10.6	26
Hogue's Yellow Dent	3	10	65.8	100	67.3	3	20	68.3	100	1	1000	30.4	100
and													
University No. 3	3	10	64.7	98	62.6	3	20	61.0	90	1	1000	30.0	99
Hogue's Yellow Dent										1	1000	27.9	100
University No. 3										1	1000	26.7	96
and													
Pride of the North										1	1000	7.7	28

*Where one plant of each of two or three varieties was grown in the same hill, the actual yield for each variety is given—based on the rate of one plant per hill.

was 100:99. Due to competition, the University No. 3 yielded relatively 8.0 per cent too low, in single rows and within the same hill it yielded 1 per cent too high. The apparent lack of competition within the hill in this case may have been due to there being only two plants of rather similar type in a hill.

When all three varieties were compared in the same hill the relative yields for the Hogue's Yellow Dent, University No. 3, and Pride of the North were respectively 100, 96, and 28, as compared with 100, 98, and 53 in the center rows of three-row plats, and 100, 90, and 38 in single-row plats.

In the three-row plats (Table 16), the yields indicate that competition affects the outer rows to such an extent that they should be discarded in all yield tests of corns which differ in growth habit. Single-row plats are unreliable for a comparative test of corn differing in growth habit or rate of planting. Two-row plats would probably be subject to one-half of the competition of single-row plats.

In 1916 (Table 17), inbred and first generation hybrid Hogue's Yellow Dent corn were similarly compared in (1) alternating single rows, (2) alternating three-row plats, and (3) in the same hill. The inbred corn had been self-fertilized

TABLE 17—*Relative yields of inbred Hogue's Yellow Dent corn and first generation hybrid seed of inbred strains when compared in three-row plats, single-row plats, and when planted in the same hill (1916)*

Manner of planting	Plants per hill	No. of replications	Yield per acre: Actual: Crossbred	Yield per acre: Actual: Inbred	Yield per acre: Relative: Crossbred	Yield per acre: Relative: Inbred
			Bushels	*Bushels*	*Per cent*	*Per cent*
Crossbred and inbred strains of H. Y. D. corn alternating in 3-row plats........	4	9	76.2	28.1	100	36.9
Crossbred and inbred strains of H. Y. D. corn alternating in single rows.........	4	6	90.5	28.0	100	31.1
Crossbred and inbred strains of H. Y. D. corn planted in the same hill*.........	4	300	54.0	11.2	100	20.7

*Where two plants each of two types were grown in the same hill, the actual yield for each type is given, based on the rate of two plants per hill.

TABLE 18—*Summary of relative grain yields when different rates of planting are tested in single-row plats and also in blocks containing several rows*

Crop tested at two rates of planting	Year of test	Ratio thick to thin	
		Alternating rows	Alternating blocks
Turkey Red winter wheat	1913	100:68	100:90
Turkey Red winter wheat	1914	100:35	100:81
Kherson Oats	1913	100:64	100:80
Kherson Oats	1914	100:67	100:102
Nebraska White Prize corn	1914	100:82	100:116
Nebraska White Prize corn	1915	100:63	100:70
Nebraska White Prize corn	1916	100:78	100:93

TABLE 19—*Summary of relative grain yields when different varieties are tested in single-row plats and also in blocks containing several rows*

Varieties compared in alternating rows and in alternating blocks	Year of test	Ratio of variety No. 1 to variety No. 2 in		
		Alternating rows	Alternating blocks	Competing in same hill (Corn)
Turkey Red (1) and Big Frame (2) winter wheat	1913	100:107	100:97	
Turkey Red (1) and Big Frame (2) winter wheat	1914	100:85	100:97	
Turkey Red (1) and Nebraska No. 28 (2) winter wheat	1913	100:107	100:107	
Turkey Red (1) and Nebraska No. 28 (2) winter wheat	1914	100:63	100:85	
Kherson (1) and Burt (2) oats	1913	100:130	100:112	
Kherson (1) and Burt (2) oats	1914	100:139	100:101	
Kherson (1) and Swedish Select (2) oats	1913	100:82	100:77	
Kherson (1) and Swedish Select (2) oats	1914	100:89	100:93	
Hogue's (1) and Pride of the North (2) corn	1912	100:66	100:85	100:47
Hogue's (1) and Pride of the North (2) corn	1914	100:38	100:53	100:26
Hogue's (1) and University No. 3 (2) corn	1914	100:90	100:98	100:99
F_1* Hogue's (1) and inbred Hogue's (2) corn	1916	100:31	100:37	100:21

*First generation hybrid of inbred strains.

for five years and was greatly reduced in size and vigor. The results indicate the error which might be expected if two inbred parents were to be compared with their hybrid and the original check seed. In alternating three-row plats, the inbred corn yielded 36.9 per cent as much as the hybrid seed, while in the alternating single-row plats it yielded 31.1 per cent as much. When compared in the same hill, the inbred seed yielded 20.7 per cent as much as the hybrid seed. Because of competition with the larger plants in the same hill, the inbred corn yielded relatively 44 per cent too low. while in alternating single rows, it yielded relatively 16 per cent too low.

SUMMARY OF PLAT COMPETITION STUDIES

The effects of single row plat competition upon comparative grain yields, are summarized for wheat, oats, and corn, in Tables 18 and 19. These data are taken from Tables 1 to 7 and 11 to 17. The ratios given for the comparative yields in blocks are for the middle row or middle three rows of either three-row plats or five-row plats, except in 1913, when the block-rows were not harvested separately.

VARIATION OF STAND AS A SOURCE OF ERROR IN YIELD TESTS WITH CORN

In order to secure information regarding the effect of variation in stand upon the accuracy of comparative corn tests, 2,000 hills of corn were planted in 1914 and 8,500 hills in 1917, in which were methodically distributed two, one and no-plant hills among hills with a full stand of three plants. Each hill was harvested separately. The results are contained in Tables 20 and 21.

In 1914 (Table 20), when surrounded by hills having a full stand of three plants, the respective relative grain yields of three-plant, two-plant and one-plant hills were 100, 82, and 74. In 1917 the corresponding relative yields were 100, 83, and 50.

In 1914 (Table 21), when three-plant corn hills, otherwise surrounded by a full stand of three plants per hill, were adjacent to (1) one hill with two plants, (2) one hill with one plant, (3) one blank hill, (4) two blank hills, the respective grain yields per hill were 3 per cent, 5 per cent, 13 per cent and 43 per cent greater than when surrounded entirely by three-plant hills.

In 1917 corresponding hills with missing plants increased the grain yields of three-plant hills respectively 2 per cent, 9 per cent, 15 per cent and 25 per cent over the yield of three-plant hills entirely surrounded by three-plant hills.

The data indicate that irregularity of stand in corn yield tests may cause inaccurate yields and should be avoided.

Error due to variation in stand of corn may be largely overcome by planting the corn thick and thinning to a uniform stand soon after coming up. If grown in hills, the seed may be space-planted in the hill so that the actual number of plants may be readily counted at harvest without suckers being mistaken for separate plants. It is desirable, just before husking, to count out a given number of hills having a full stand and surrounded by a normal stand, upon which to base the yield per acre. This may be facilitated by planting an additional number of hills to permit discarding. Space-planting in the hill for experimental yield tests may be accomplished by first marking off the field crosswise with a sled marker and then making three separate spaced plantings in each intersection by means of a hand corn planter adapted for the purpose. Where three plants are grown per hill, the marker runners should be double so that all three plantings may be made in a runner mark, thus insuring uniform planting conditions for all three plants. There are exceptional kinds of corn experiments in which planting thick and thinning to insure a perfect stand would conflict with the object of the investigation.

TABLE 20—*Relative yields of one, two, and three-plant corn hills when surrounded uniformly by three-plant hills (1914 and 1917)*

Number of plants in hills surrounded by uniform three-plant hills	Number of hills averaged	Number of tillers per 100 plants	Number of ears per 100 plants	Average grain yield per hill	
				Actual	Relative
				Grams	*Per cent*
		YEAR 1914			
Hills with three plants..	310	8	83	466	100
Hills with two plants...	70	38	96	380	82
Hills with one plant....	16	112	168	344	74
		YEAR 1917			
Hills with three plants..	288	....	95	509	100
Hills with two plants...	50	....	102	422	83
Hills with one plant....	64	....	114	252	50

TABLE 21—*Relative yields of three-plant corn hills adjacent to hills with missing plants (1914 and 1917)*

Three-plant hills surrounded by three-plant hills except as indicated below	Number of hills averaged	Number of plants per hill	Number of ears per 100 plants	Average grain yield of three-plant hills	
				Actual	Relative
				Grams	*Per cent*
YEAR 1914					
Surrounded by hills with three plants..........	310	3	83.6	465.8	100
Adjacent to one hill with two plants...........	149	3	87.0	478.2	103
Adjacent to one hill with one plant...........	44	3	86.3	490.3	105
Adjacent to one blank hill..................	132	3	88.0	526.6	113
Adjacent to two blank hills................	57	3	91.0	666.5	143
YEAR 1917					
Surrounded by hills with three plants..........	288	3	95	509	100
Adjacent to one hill with two plants...........	211	3	96	519	102
Adjacent to one hill with one plant...........	258	3	102	555	109
Adjacent to one blank hill..................	234	3	99	585	115
Adjacent to two blank hills................	198	3	101	631	125

RELATION OF STAND TO YIELD IN SINGLE-ROW TEST PLATS

The data in Table 22 were compiled from records of extensive ear-to-row tests of Hogue's Yellow Dent corn made by Lyon and Montgomery at the Nebraska Station during the four years 1904-1907. Rows 72 hills in length had been planted by hand at the rate of three kernels per hill, 3 feet 8 inches apart. The entire plats were harvested regardless of the actual stand secured, altho a record was taken of the per cent stand.

In Table 22 the plat yields have been assembled into groups for each year according to the per cent stand. Since a rather large number of plats are averaged in each group, this may overcome in large measure any inherent difference in yielding power of the individual ears tested, and the differ-

TABLE 22—*Relation of per cent germination in the field to yield of single-row test plats of Hogue's Yellow Dent corn (1904-1907)*

Year	Number of plats averaged	Kernels planted per hill	Average field germination	Yield per acre
			Per cent	*Bushels*
GERMINATION 90-95 PER CENT				
1904	10	3	92.1	76.8
1905	9	3	92.3	94.6
1906	2	3	93.0	84.8
1907	22	3	94.0	85.9
Average	43	3	92.8	85.5
GERMINATION 85-90 PER CENT				
1904	12	3	87.6	81.3
1905	25	3	88.1	95.2
1906	10	3	87.0	92.4
1907	16	3	86.0	83.7
Average	63.	3	87.2	88.1
GERMINATION 80-85 PER CENT				
1904	27	3	83.1	75.4
1905	40	3	83.2	88.4
1906	32	3	82.6	85.4
1907	18	3	82.0	85.0
Average	117	3	82.7	83.5
GERMINATION 75-80 PER CENT				
1904	12	3	78.0	76.2
1905	14	3	78.4	85.5
1906	18	3	78.0	83.3
1907	16	3	77.0	83.9
Average	60.	3	77.8	82.2
GERMINATION 70-75 PER CENT				
1904	11	3	74.0	68.1
1905	6	3	73.2	79.9
1906	19	3	73.4	82.9
1907	10	3	72.0	80.6
Average	46.	3	73.1	77.9
GERMINATION 60-70 PER CENT				
1904	13	3	66.2	67.3
1905	3	3	67.3	77.3
1906	10	3	68.1	80.1
1907	10	3	65.0	74.7
Average	36.	3	66.6	74.8
GERMINATION BELOW 60 PER CENT				
1904	21	3	35.6	42.6
1905	6	3	51.5	70.7
1906	11	3	42.1	56.9
1907	7	3	43.0	56.8
Average	45	3	43.0	56.7

ence in yield for the groups may be assigned primarily to the difference in stand. During the four years, considering three plants per hill a 100 per cent stand, stands averaging 92.8, 87.2, 82.7, 77.8, 73.1, 66.6, and 43.0 per cent yielded respectively 85.5, 88.1, 83.5, 82.2, 77.9, 74.8, and 56.7 bushels per acre.

It appears from these results that what was regarded a perfect stand, namely three plants per hill, was too thick for a maximum yield with this variety, since an 87.2 per cent stand outyielded a 92.8 per cent stand. The yield by no means decreased in proportion to the stand. An average stand of 43 per cent yielded 66.3 per cent as much as a 92.8 per cent stand. It would appear unreliable to correct yields upon a basis of stand.

The yield of an individual row plat planted at a given rate will vary greatly according to the stand in adjacent rows. For this reason the data in Table 22 must not be regarded as necessarily indicating the true relative yields, during the years tested, for the different stands as would be obtained in a proper rate-of-planting test.

Because of the chance variations in stand of single-row plats, no reliable formulas can be established for the correction of yields according to the per cent stand. For example, very different results may be expected from a row with 75 per cent stand, according to whether it falls between rows having a 50 per cent or a 100 per cent stand. This is borne out by the rate-of-planting tests in rows and blocks during the three years 1914-1916 (Tables 11, 12, and 13).

COMBINATION OF RATE-PLANTING AND VARIETY YIELD TESTS

It has been a rather common practice in variety yield tests to plant all varieties at one arbitrary "standard" rate, regardless of their growth habits.

During 1907 and 1908, three varieties were tested at five different rates of planting. The Pride of the North and Calico, which are respectively small and medium-sized varieties, increased regularly in yield with the rate of planting, and produced their maximum at the rate of five plants per hill. On the other hand, Mammoth White Pearl, which is a large late corn, yielded its maximum at the three-rate and then fell off sharply.

In 1914, three varieties, differing distinctly in size and length of growing season, were planted at five different rates. Pride of the North produced its maximum yield at the rate of five plants per hill. University No. 3 produced identical and maximum yields at both the two and the three-rate and then fell off sharply. Hogue's Yellow Dent produced its maximum yield at the two-rate and then fell off sharply.

The data in both Tables 23 and Table 24 indicate that the relative yielding power of varieties differing in growth habit can only be determined by planting at several rates. Different varieties have a different optimum rate of planting.

TABLE 23—*Relation of rate of planting to yield of corn varieties differing in growth habit grown in two-row plats* (1907-1908)*

Plants per hill	Length growing period	Yield per acre		
		1907	1908	Average
	Days	*Bushels*	*Bushels*	*Bushels*
PRIDE OF THE NORTH				
1	127	33.7	25.0	29.3
2	126	48.2	37.5	42.8
3	126	55.3	45.5	50.0
4	125	63.8	51.6	57.7
5	125	69.4	48.4	58.9
CALICO				
1	127	43.1	28.1	35.6
2	125	53.4	40.6	47.0
3	126	71.0	53.1	62.0
4	125	74.8	56.2	65.5
5	124	78.7	64.1	71.4
MAMMOTH WHITE PEARL				
1	135	45.6	43.8	44.7
2	135	59.1	65.6	62.3
3	134	70.7	71.9	71.3
4	133	52.0	59.4	55.7
5	133	61.1	56.2	58.6

*Plats not duplicated.

EFFECT OF REMOVING SUCKERS WITH DIFFERENT VARIETIES

Occasionally an investigator has removed the suckers from his corn varieties or selections in order to avoid annoyance by them. The data in Table 25 indicate that the removal of suckers may affect different varieties differently, and that a new error in testing may be introduced thereby.

TABLE 24—*Relation of rate of planting to yield of corn varieties differing in growth habit grown in three-row plats (1914)*

Plants per hill	No. of replications	Length growing Period	Barren stalks	Two-eared stalks	No. of ear bearing suckers per 100 plants	Yield per acre (center row)
		Days	*Per cent*	*Per cent*		*Bushels*
			PRIDE OF THE NORTH			
1	3	92	0	8	7	17.4
2	3	92	0	1	2	28.2
3	3	92	2	0	0	35.5
4	3	92	2	0	0	39.8
5	3	92	8	0	0	44.4
			UNIVERSITY NO. 3			
1	3	107	0	14	20	40.2
2	3	107	1	3	2	59.6
3	3	107	6	1	0	59.5
4	3	107	8	0	0	52.7
5	3	107	15	0	0	47.3
			HOGUE'S YELLOW DENT			
1	3	119	0	10	19	44.4
2	3	119	1	1	2	63.9
3	3	119	2	0	0	59.0
4	3	119	7	0	0	59.8
5	3	119	13	0	0	53.7

RELIABILITY OF ESTIMATING PLAT YIELDS BY MEANS OF FRACTIONAL AREAS

In conducting field experiments in cooperation with farmers, experiment stations frequently encounter difficulty in having test plats properly harvested and threshed. In some states the yields of such plats are estimated by harvesting a number of very small apparently representative areas from each of the plats to be compared. The small quantity

TABLE 25—*Effect of removing tillers from corn varieties differing in growth habits (1912 and 1914)*

Variety	Plants per hill	No. of replications	Yield per acre*		
			Tillers on	Tillers removed	Difference
			Bushels	*Bushels*	*Bushels*
		YEAR 1912			
Pride of the North..........	2	10	38.6	30.9	7.7
University No. 3............	2	10	47.7	42.9	4.8
Hogue's Yellow Dent........	2	10	53.7	43.5	10.2
Pride of the North..........	3	10	40.9	38.2	2.7
University No. 3............	3	10	56.9	54.2	2.7
Hogue's Yellow Dent........	3	10	43.6	38.8	4.8
		YEAR 1914			
Pride of the North..........	2	3	35.3	32.5	2.8
University No. 3............	2	3	49.2	50.5	+1.3
Hogue's Yellow Dent	2	3	52.3	55.0	+2.7
Pride of the North..........	3	3	38.8	33.6	5.2
University No. 3............	3	3	45.8	46.6	+0.8
Hogue's Yellow Dent........	3	3	54.4	54.3	0.1

*Yield per acre based on center row of three-row plats in 1914 and on single-row plats in 1912.

of grain harvested in this manner can readily be shipped to the central station for threshing and estimation of yield. In order to secure information relative to the reliability of such a method the following test was made in 1917:

Duplicate thirtieth-acre field plats of each of seven different varieties or selections of winter wheat were chosen from among a large number of plats for this study. These plats measured 16 rods by 66 inches and contained eight rows.

Twenty systematically distributed fractional areas or quadrates were harvested from each plat. These were 32 inches square, contained four rows of wheat, and were .0001632 acre in area. Quadrates were located 10 feet from each end and at intervals of 14 feet on alternate sides of the plat, as indicated in the following diagram.

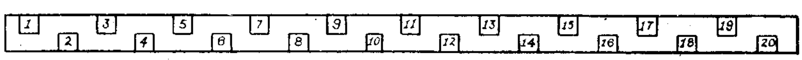
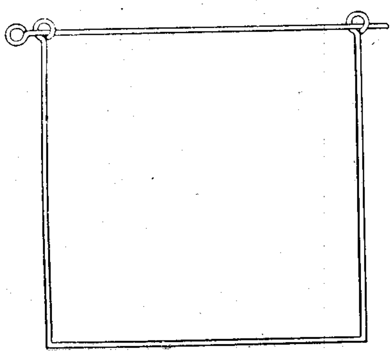


Diagram showing distribution of 20 quadrates in thirtieth-acre plats (Table 26)

The quadrates were accurately laid out by means of an iron frame, as shown in the following figure. A rectangular frame is more reliable than a round one where the grain is planted in rows.



Frame used for laying off quadrates (Table 26)

Because of severe and variable winterkilling the 14 plats differed markedly in the percentage of plants surviving, and in yield. There was also much greater variation between the quadrates within a single plat than would normally be expected.

Opportunity was provided to compare the mean results of 5, 10, and 20 systematically distributed quadrates with the entire plat from which they were harvested. In making four groups of five quadrates each, group (a) contained quadrates Nos. 1, 6, 9, 14, and 17; group (b) contained Nos. 3, 8, 11, 16, and 19; group (c) contained Nos. 2, 5, 10, 13, and 18; and group (d) Nos. 4, 7, 12, 15, and 20. For two groups of 10 quadrates each, group (a) contained Nos. 1, 4, 5, 8, 9, 12, 13, 16, 17, and 20, and group (b) contained Nos. 2, 3, 6, 7, 10, 11, 14, 15, 18, and 19. The results of these various groupings are shown in Table 26 in comparison with the yields of the entire respective plats.

The average yield determined from 20 quadrates deviated 1.4 bushels from the average plat yield.

For individual plats the 20-quadrate yield estimation varied from 0.2 to 3.2 bushels per acre.

Since each kind of wheat was grown in duplicate plats the mean of 40 quadrates can be compared with the mean of two field plats. In this comparison the average of these

TABLE 26—*Comparative yield of grain per acre from winter wheat plats and from systematically distributed fractional areas harvested within the plats (1917)*

CLASSIFICATION	Group number	Turkey Red No. 42		Turkey Red No. 48		Turkey Red No. 6		Turkey Red No. 60		Turkey Red No. 78		Original Turkey Red		Kharkov	
		Plat 2	Plat 30	Plat 3	Plat 31	Plat 4	Plat 32	Plat 10	Plat 38	Plat 12	Plat 40	Plat 13	Plat 41	Plat 22	Plat 50
Field Plat		*Bus.* 27.9	*Bus.* 41.2	*Bus.* 33.2	*Bus.* 41.8	*Bus.* 35.4	*Bus.* 44.3	*Bus.* 40.3	*Bus.* 49.2	*Bus.* 15.1	*Bus.* 20.9	*Bus.* 35.7	*Bus.* 38.5	*Bus.* 34.0	*Bus.* 37.4
Five quadrates in a group	a	29.2	41.0	28.8	45.3	35.1	51.3	40.9	45.7	10.3	24.2	42.3	44.1	38.2	35.3
	b	27.9	42.1	35.4	45.5	33.0	48.0	39.3	49.5	11.3	25.8	31.4	35.9	38.1	38.5
	c	26.4	41.5	30.1	40.6	32.5	36.0	35.1	47.7	9.1	14.0	35.8	44.1	34.8	41.8
	d	29.7	41.1	31.2	39.8	38.6	44.1	35.3	49.1	18.0	28.7	35.6	33.2	37.9	38.4
Average		28.3	41.4	31.3	42.8	34.8	44.8	37.6	48.0	12.2	23.2	36.3	39.3	37.2	38.5
Ten quadrates in a group	a	31.1	38.5	32.1	43.2	36.9	45.5	38.8	45.4	13.1	25.0	37.8	38.6	39.3	36.8
	b	25.5	44.3	30.6	42.4	32.7	44.2	36.5	50.5	11.3	21.4	34.7	40.1	35.2	40.1
Average		28.3	41.4	31.3	42.8	34.8	44.8	37.6	48.0	12.2	23.2	36.3	39.3	37.2	38.5
Twenty quadrates in a group		28.3	41.4	31.3	42.8	34.8	44.8	37.6	48.0	12.2	23.2	36.3	39.3	37.2	38.5
Average of two field plats		34.5		37.5		39.8		44.7		18.0		37.1		35.7	
Average of 40 quadrates		34.8		37.1		39.8		42.8		17.7		37.8		37.8	
Deviation of quadrates from field plats		+ 0.3		— 0.4		0.0		— 1.9		— 0.3		+ 0.7		+ 2.1	

quadrate means, for the several sorts of wheat, deviated 2.2 per cent from the average of the duplicate plat yields.

When the quadrates from each plat were grouped into sets of five and ten each, there was considerable variation in yield between the separate groups, which suggests that not less than 20 quadrates should be harvested from comparative plats of this character.

It appears that the results from 20 systematically distributed quadrates may be fairly safely substituted for the yield of the entire plat from which they are taken.

EXPERIMENTAL ERRORS CAUSED BY SOIL VARIATION

The lack of uniformly productive land for comparative crop tests has given rise to a number of methods frequently used for ascertaining and overcoming the resultant experimental error. Chief among these methods are: (1) The use of frequent, systematically distributed check plats planted to a uniform crop for the purpose of (a) indicating the degree

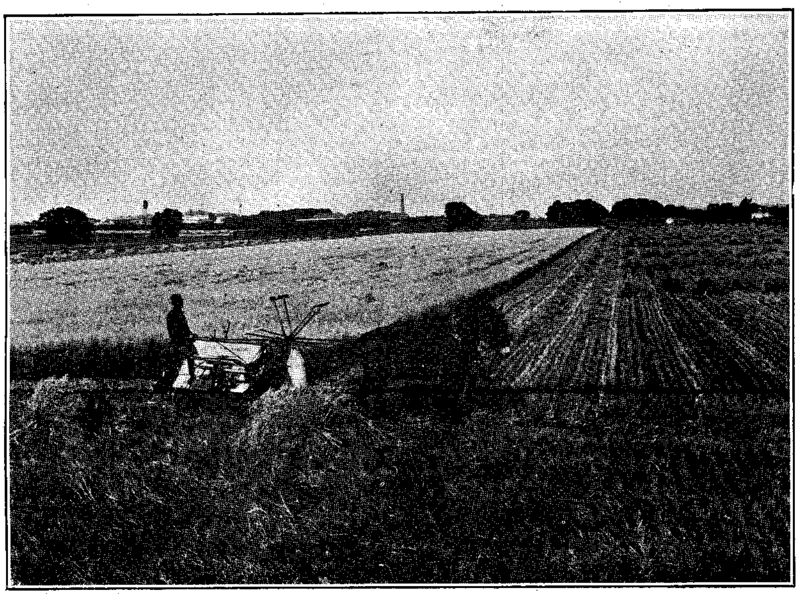


Fig. 13—A relatively uniform field containing 207 thirtieth-acre plats sown for a method study to a uniform crop of Kherson oats (1916)

of variation due to the soil or (b) correcting the results from the intervening test plats. (2) Replication of plats and basing the conclusions upon the mean yield. (3) Use of long, narrow rather than short, wide plats. (4) Calculating the probable error for the mean results of replicated plats, to indicate the degree of confidence which may be placed in the results.

The results from 207 thirtieth-acre Kherson oats plats, grown in 1916, illustrate each of the four practices mentioned above. These plats were planted to a uniform crop upon a seemingly uniform field for the purpose of studying variation in plat yields as a source of experimental error. The

Fig. 14—Two hundred and seven thirtieth-acre Kherson oats plats planted to a uniform crop for studying experimental error in 1916

entire field had been cropped uniformly to silage corn for a period of eight years. It had been plowed each year and was also plowed in preparation for the oats in 1916. The oats were drilled during two successive days in plats 16 rods by 66 inches, which equaled one drill width. The plats were separated by a space of 16 inches between outside drill rows. A wide discard border of oats was grown around the outer edge of the field, so that all plats should have a similar exposure. General views of this field are shown in Figures 13 and 14.

USE OF CHECK PLATS

During the past 15 years it has become the general practice in crop investigations to plant check plats at regular stated intervals. These plats are planted to a uniform crop and should yield alike except for various environmental sources of experimental error.

The use of check plats may be twofold: (1) To indicate the error caused by variation in normal plat yields. The variation in the check plats is regarded as indicative of the error in the test plats. (2) Check plats are more commonly used to calculate the normal or theoretical yield of all plats in the field. All crops or treatments are then compared directly with each other by their increased or decreased yield above or below the calculated normal yield for the plats upon which they grew. This difference is best expressed in percentage of the normal plat yield. Comparative yields per acre may then be calculated for each crop, variety, or treatment by adding (or subtracting) the difference between it and the normal yield for the plat to (or from) the mean yield for all check plats in the field. This recalculation of yields is usually spoken of as correction according to check plats.

The check plats may be variously distributed in the field according to the manner in which the corrections are to be made. Three methods of correction are in common use: (1) The normal or theoretical yield of the test plat is determined by, and is equivalent to, the average of two adjacent check plats. (Alternating plats are check plats.) (2) The normal or theoretical yield of the test plat is determined by, and is equivalent to, the yield of a single adjacent check plat. (Two test plats are planted between checks.) (3) The soil between two or more check plats is regarded as varying gradually from one check plat to the other and a progressive correction is used to establish the normal or theoretical yields of the intervening test plats. Thus, if two test plats lie between checks which yield 51 and 60 bushels respectively, the normal yields assigned to the two test plats by this progressive method would be 54 and 57 bushels. Progressing from the lower to the higher yielding check the normal yield of the first test plat is greater than the poorer check by one-third of the difference, while the normal yield of the second test plat is greater than the poorer check by two-thirds of the difference. The proportion of the difference added to each successive test plat will depend upon the number of plats between checks.

TABLE 27—*Two hundred and seven thirtieth-acre Kherson oats plats calculated to show use of alternating check plats for correction of yields**

Plat No.	Yield per acre		Deviation from normal		Corrected yield	Plat No.	Yield per acre		Deviation from normal		Corrected yield	Plat No.	Yield per acre		Deviation from normal		Corrected yield
	Actual	Normal					Actual	Normal					Actual	Normal			
	Bus.	*Bus.*	*Bushels*	*Per cent*	*Bushels*		*Bus.*	*Bus.*	*Bushels*	*Per cent*	*Buehels*		*Bus.*	*Bus.*	*Bushels*	*Per cent*	*Bushels*
1 ck	75.5				78.2	138 ck	87.2				78.2	139 ck	81.6				78.2
2	84.8	80.9	+ 3.9	+ 4.82	82.0	137	81.9	86.0	— 4.1	— 4.77	74.5	140	83.0	82.8	+ 0.2	+ 0.24	78.4
3 ck	86.3				78.2	136 ck	84.8				78.2	141 ck	83.9				78.2
4	84.4	85.6	— 1.2	— 1.40	77.1	135	84.4	86.0	— 1.6	— 1.86	76.8	142	75.5	80.6	— 5.1	— 6.33	73.3
5 ck	84.8				78.2	134 ck	87.2				78.2	143 ck	77.3				78.2
6	85.3	83.2	+ 2.1	+ 2.52	80.2	133	82.0	86.3	— 4.3	— 4.98	74.3	144	76.9	77.1	— 0.2	— 0.26	78.0
7 ck	81.6				78.2	132 ck	85.3				78.2	145 ck	76.9				78.2
8	84.8	80.9	+ 3.9	+ 4.82	82.0	131	82.0	81.3	+ 0.7	+ .86	78.9	146	82.0	76.0	+ 6.0	+ 7.90	84.4
9 ck	80.2				78.2	130 ck	77.3				78.2	147 ck	75.0				78.2
10	79.7	79.7	0.0	0.0	78.2	129	79.8	78.8	+ 1.0	+ 1.27	79.2	148	75.5	75.3	+ 0.2	+ 0.27	78.4
11 ck	79.2				78.2	128 ck	80.2				78.2	149 ck	75.5				78.2
12	83.0	79.7	+ 3.3	+ 4.14	81.4	127	82.2	72.5	+ 9.7	+13.38	88.7	150	74.1	72.7	+ 1.4	+ 1.93	79.7
13 ck	80.2				78.2	126 ck	64.7				78.2	151	69.8				78.2
14	86.3	80.7	+ 5.6	+ 6.94	83.6	125	70.8	72.0	— 1.2	— 1.67	76.9	152	71.7	73.8	— 2.1	— 2.85	76.0
15 ck	81.1				78.2	124 ck	79.2				78.2	153 ck	77.8				78.2
16	77.8	78.3	— 0.5	— .64	77.7	123	77.8	77.4	+ 0.4	+ .52	78.6	154	75.9	75.3	+ 0.6	+ .80	78.8
17 ck	75.5				78.2	122 ck	75.5				78.2	155 ck	72.7				78.2
18	68.4	77.2	— 8.8	—11.40	69.3	121	88.1	81.6	+ 6.5	+ 7.97	84.4	156	73.1	73.9	— 0.8	— 1.08	77.4
19 ck	78.8				78.2	120 ck	87.7				78.2	157 ck	75.0				78.2
20	80.6	80.7	— 0.1	— .12	78.1	119	88.6	84.7	+ 3.9	+ 4.60	81.8	158	78.8	76.0	+ 2.8	+ 3.68	81.1
21 ck	82.5				78.2	118 ck	81.6				78.2	159 ck	76.9				78.2
22	85.3	80.7	+ 4.6	+ 5.70	82.7	117	85.3	81.8	+ 3.5	+ 4.28	81.5	160	72.7	76.4	— 3.7	— 4.84	74.4
23 ck	78.8				78.2	116 ck	82.0				78.2	161 ck	75.9				78.2
24	80.2	78.8	+ 1.4	+ 1.78	79.6	115	75.0	79.0	— 4.0	— 5.06	74.2	162	75.9	78.3	— 2.4	— 3.07	75.8
25 ck	78.8				78.2	114 ck	75.9				78.2	163 ck	80.6				78.2
26	85.8	71.8	+14.0	+19.50	93.5	113	89.1	80.2	+ 8.9	+11.10	86.9	164	78.8	78.3	+ 0.5	+ .64	78.7
27 ck	64.7				78.2	112 ck	84.4				78.2	165 ck	75.9				78.2
28	88.1	70.8	+17.3	+24.44	97.3	111	86.3	86.3	0.0	0.0	78.2	166	75.5	73.6	+ 1.9	+ 2.58	80.2
29 ck	76.9				78.2	110 ck	88.1				78.2	167 ck	71.3				78.2
30	83.4	78.8	+ 4.6	+ 5.84	82.8	109	79.2	84.4	— 5.2	— 6.16	73.4	168	72.2	72.0	+ 0.2	+ .28	78.4
31 ck	80.6				78.2	108 ck	80.6				78.2	169 ck	72.7				78.2
32	79.7	82.0	— 2.3	— 2.81	76.0	107	86.7	81.1	+ 5.6	+ 6.91	83.6	170	72.2	75.0	— 2.8	— 3.73	75.3
33 ck	83.4				78.2	106 ck	81.6				78.2	171 ck	77.3				78.2

34	81.1	83.0	— 1.9	— 2.29	76.4	105	82.0	81.6	+ 0.4	+ .49	78.6	172	78.3	78.1	+ 0.2	+ .26	78.4
35 ck	82.5				78.2	104 ck	81.6				78.2	173 ck	78.8				78.2
36	80.2	81.1	— 0.9	— 1.11	77.3	103	89.5	78.8	+10.7	+13.58	88.8	174	75.9	78.8	— 2.9	—3.68	75.3
37 ck	79.7				78.2	102 ck	75.9				78.2	175 ck	78.8				78.2
38	81.6	81.6	0.0	0.0	78.2	101	71.3	74.8	— 3.5	— 4.68	74.5	176	80.6	74.8	+ 5.8	+ 7.75	84.3
39 ck	83.4				78.2	100 ck	73.6				78.2	177 ck	70.8				78.2
40	78.8	85.1	— 6.3	— 7.40	72.4	99	83.0	71.3	+11.7	+16.41	91.0	178	72.7	74.6	— 1.9	— 2.55	76.2
41 ck	86.7				78.2	98 ck	68.9				78.2	179 ck	78.3				78.2
42	82.5	86.3	— 3.8	— 4.40	74.8	97	73.6	76.7	— 3.1	— 4.04	75.0	180	77.3	80.0	— 2.7	— 3.38	75.6
43 ck	85.8				78.2	96 ck	84.4				78.2	181 ck	81.6				78.2
44	78.8	82.8	— 4.0	— 4.83	74.4	95	76.9	83.2	— 6.3	— 7.57	72.3	182	74.1	78.6	— 4.5	— 5.73	73.7
45 ck	79.7				78.2	94 ck	82.0				78.2	183 ck	75.5				78.2
46	69.4	79.3	— 9.9	—12.48	68.4	93	71.7	77.4	— 5.7	— 7.36	72.4	184	72.7	78.8	— 6.1	— 7.74	72.2
47 ck	78.8				78.2	92 ck	72.7				78.2	185 ck	82.0				78.2
48	83.0	79.3	+ 2.7	+ 3.41	80.9	91	74.5	72.9	+ 1.6	+ 2.19	79.9	186	65.6	76.7	—11.1	—14.47	66.9
49 ck	79.7				78.2	90 ck	73.1				78.2	187 ck	71.3				78.2
50	82.5	82.5	0.0	0.0	78.2	89	71.3	70.1	+ 1.2	+ 1.71	79.5	188	64.7	70.8	— 6.1	— 8.62	71.5
51 ck	85.3				78.2	88 ck	67.0				78.2	189 ck	70.3				78.2
52	83.9	84.4	— 0.5	— .59	77.7	87	67.0	73.6	— 6.6	— 8.97	71.2	190	68.4	73.1	— 4.7	— 6.43	73.2
53 ck	83.4				78.2	86 ck	80.2				78.2	191 ck	75.9				78.2
54	81.6	79.2	+ 2.4	+ 3.03	80.6	85	70.3	78.8	— 8.5	—10.79	69.8	192	79.2	72.7	+ 6.5	+ 8.94	85.2
55 ck	75.0				78.2	84 ck	77.3				78.2	193 ck	69.4				78.2
56	75.0	79.2	— 4.2	— 5.30	74.1	83	73.6	79.2	— 5.6	— 7.07	72.7	194	73.1	68.2	+ 4.9	+ 7.19	83.8
57 ck	83.4				78.2	82 ck	81.1				78.2	195 ck	67.0				78.2
58	85.3	79.9	+ 5.4	+ 6.76	83.5	81	73.6	78.1	— 4.5	— 5.76	73.7	196	82.5	69.2	+13.3	+19.22	93.2
59 ck	76.4				78.2	80 ck	75.0				78.2	197 ck	71.3				78.2
60	69.4	79.0	— 9.6	—12.15	68.7	79	78.8	77.1	+ 1.7	+ 2.20	79.9	198	71.3	64.0	+ 7.3	+11.41	87.1
61 ck	81.6				78.2	78 ck	79.2				78.2	199 ck	56.7				78.2
62	78.3	80.7	— 2.4	— 2.97	75.9	77	81.1	86.0	— 4.9	— 5.70	73.7	200	57.7	60.3	— 2.6	— 4.31	74.8
63 ck	79.7				78.2	76 ck	92.8				78.2	201 ck	63.8				78.2
64	80.6	79.5	+ 1.1	+ 1.38	79.3	75	79.2	88.8	— 9.6	—10.81	69.7	202	66.6	67.1	— 0.5	— 0.75	77.6
65 ck	79.2				78.2	74 ck	84.8				78.2	203 ck	70.3				78.2
66	76.9	78.1	— 1.2	— 1.54	77.0	73	82.5	86.5	— 4.0	— 4.62	74.6	204	68.4	75.1	— 6.7	— 8.92	71.2
67 ck	76.9				78.2	72 ck	88.1				78.2	205 ck	79.8				78.2
68	83.0	75.3	— 7.7	—10.23	70.2	71	85.3	83.5	+ 1.8	+ 2.16	79.9	206	78.8	77.4	+ 1.4	+ 1.81	79.6
69 ck	73.6				78.2	70 ck	78.8				78.2	207 ck	75.0				78.2

*The plats are arranged in this table in the same relative position as they occurred in the field.

TABLE 28—*Two hundred and seven thirtieth-acre Kherson oats plats calculated to show use of one adjacent check plat for correction of yields*

Plat No.	Yield per acre		Deviation from normal		Corrected yield	Plat No.	Yield per acre		Deviation from normal		Corrected yield	Plat No.	Yield per acre		Deviation from normal		Corrected yield
	Actual	Normal					Actual	Normal					Actual	Normal			
	Bus.	*Bus.*	*Bushels*	*Per cent*	*Bushels*		*Bus.*	*Bus.*	*Bushels*	*Per cent*	*Bushels*		*Bus.*	*Bus.*	*Bushels*	*Per cent*	*Bushels*
1	75.5	84.3	— 9.3	—10.97	69.6	138	87.2	89.1	— 1.9	— 2.13	76.5	139	81.6	83.0	— 1.4	— 1.69	76.9
2 ck	84.8				78.2	137 ck	89.1				78.2	140 ck	83.0				78.2
3	86.3	84.8	+ 1.5	+ 1.77	79.6	136	84.8	89.1	— 4.3	— 4.83	74.4	141	83.9	83.0	+ 0.9	+ 1.08	79.0
4	84.4	84.8	— 0.4	— 0.47	77.8	135	84.4	87.2	— 2.8	— 3.21	75.7	142	75.5	77.3	— 1.8	— 2.33	76.4
5 ck	84.8				78.2	134 ck	87.2				78.2	143 ck	77.3				78.2
6	85.3	84.8	+ 0.5	+ 0.59	78.7	133	82.0	87.2	— 5.2	— 5.96	73.5	144	76.9	77.3	— 0.4	— .52	77.8
7	81.6	84.8	— 3.2	— 3.77	75.3	132	85.3	82.0	— 3.3	+ 4.02	81.3	145	76.9	82.0	— 5.1	— 6.22	73.3
8 ck	84.8				78.2	131 ck	82.0				78.2	146 ck	82.0				78.2
9	80.2	84.8	— 4.6	— 5.42	74.0	130	77.3	82.0	— 4.7	— 5.73	73.7	147	75.0	83.0	— 7.0	— 8.54	71.5
10	79.7	79.2	+ 0.5	+ 0.63	78.7	129	79.8	80.2	— 0.4	— 0.50	77.8	148	75.5	75.5			78.8
11 ck	79.2				78.2	128 ck	80.2				78.2	149 ck	75.5				78.2
12	83.0	79.2	+ 3.8	+ 4.80	82.0	127	82.2	80.2	+ 2.0	+ 2.49	80.1	150	74.1	75.5	— 1.4	— 1.85	76.8
13	80.2	86.3	— 6.1	— 7.07	72.7	126	64.7	70.8	— 6.1	— 8.62	71.5	151	69.8	71.7	— 1.9	— 2.65	76.1
14 ck	86.3				78.2	125 ck	70.8				78.2	152 ck	71.7				78.2
15	81.1	86.3	— 5.2	— 6.03	73.5	124	79.2	70.8	+ 8.4	+11.86	87.5	153	77.8	71.7	+ 6.1	+ 8.51	84.9
16	77.8	75.5	+ 2.3	+ 3.05	80.6	123	77.8	75.5	+ 2.3	+ 3.05	80.6	154	75.7	75.9	+ 3.2	+ 4.40	81.6
17 ck	75.5				78.2	122 ck	75.5				78.2	155 ck	72.7				78.2
18	68.4	75.5	— 7.1	— 9.40	70.9	121	88.1	75.5	+12.6	+16.69	91.3	156	73.1	72.7	+ 0.4	+ .55	78.6
19	78.8	80.6	— 1.8	— 2.23	76.5	120	87.7	88.6	— 0.9	— 1.02	77.4	157	75.0	78.8	— 3.8	— 4.82	74.4
20 ck	80.6				78.2	119 ck	88.6				78.2	158 ck	78.8				78.2
21	82.5	80.6	+ 1.9	+ 2.36	80.1	118	81.6	88.6	— 7.0	— 7.90	72.0	159	76.9	78.8	— 1.9	— 2.41	76.3
22	85.3	78.8	+ 6.5	+ 8.25	84.7	117	85.3	82.0	+ 3.3	+ 4.02	81.3	160	72.7	75.9	— 3.2	— 4.22	74.9
23 ck	78.8				78.2	116 ck	82.0				78.2	161 ck	75.9				78.2
24	80.2	78.8	+ 1.4	+ 1.78	79.6	115	75.0	82.0	— 7.0	— 8.54	71.5	162	75.9	75.9			78.2
25	78.8	85.8	— 7.0	— 8.16	71.8	114	75.9	89.1	—13.2	—14.81	66.6	163	80.6	78.8	+ 1.8	+ 2.28	80.0
26 ck	85.8				78.2	113 ck	89.1				78.2	164 ck	78.8				78.2
27	64.7	85.8	—21.1	—24.59	59.0	112	84.4	89.1	— 4.7	— 5.28	74.1	165	75.9	78.8	— 2.9	— 3.68	75.3
28	88.1	76.9	+11.2	+14.56	89.6	111	86.3	88.1	— 1.8	— 2.04	76.6	166	75.5	71.3	+ 4.2	+ 5.89	82.8
29 ck	76.9				78.2	110 ck	88.1				78.2	167 ck	71.3				78.2
30	83.4	76.9	+ 6.5	+ 8.45	84.8	109	79.2	88.1	— 8.9	—10.10	70.3	168	72.2	71.3	+ 0.9	+ 1.26	79.2
31	80.6	79.7	+ 0.9	+ 1.13	79.1	108	80.6	86.7	— 6.1	— 7.04	72.7	169	72.7	72.2	+ 0.5	+ 0.69	78.7
32 ck	79.7				78.2	107 ck	86.7				78.2	170 ck	72.2				78.2
33	83.4	79.7	+ 3.7	+ 4.64	81.8	106	81.6	86.7	— 5.1	— 5.88	73.6	171	77.3	72.2	+ 5.1	+ 7.06	83.7

34	81.1	82.5	— 1.4	— 1.70	76.9	105	82.0	81.6	+ 0.4	+ 0.49	78.6	172	78.3	78.8	— 0.5	— 0.63	77.7
35 ck	82.5				78.2	104 ck	81.6				78.2	173 ck	78.8				78.2
36	80.2	82.5	— 2.3	— 2.79	76.0	103	89.5	81.6	+ 7.9	+ 9.68	85.8	174	75.9	78.8	— 2.9	— 3.68	75.3
37	79.7	81.6	— 1.9	— 2.33	76.4	102	75.9	71.3	+ 4.6	+ 6.45	83.3	175	78.8	80.6	— 1.8	— 2.23	76.5
38 ck	81.6				78.2	101 ck	71.3				78.2	176 ck	80.6				78.2
39	83.4	81.6	+ 1.8	+ 2.21	79.9	100	73.6	71.3	+ 2.3	+ 3.23	80.7	177	70.8	80.6	— 9.8	—12.16	68.7
40	78.8	86.7	— 7.9	— 9.11	71.1	99	83.0	68.9	+14.1	+20.47	94.2	178	72.7	78.3	— 5.6	— 7.15	72.6
41 ck	86.7				78.2	98 ck	68.9				78.2	179 ck	78.3				78.2
42	82.5	86.7	— 4.2	— 4.84	74.4	97	73.6	68.9	+ 4.7	+ 6.82	83.5	180	77.3	78.3	— 1.0	— 1.28	77.2
43	85.8	78.8	+ 7.0	+ 8.88	85.1	96	84.4	76.9	+ 7.5	+ 9.75	85.8	181	81.6	74.1	+ 7.5	+10.12	86.1
44 ck	78.8				78.2	95 ck	76.9				78.2	182 ck	74.1				78.2
45	79.7	78.8	+ 0.9	+ 1.14	79.1	94	82.0	76.9	+ 5.1	+ 6.63	83.4	183	75.5	74.1	+ 1.4	+ 1.89	79.7
46	69.4	78.8	— 9.4	—11.93	68.9	93	71.7	72.7	— 1.0	— 1.38	77.1	184	72.7	82.0	— 9.3	—11.34	69.3
47 ck	78.8				78.2	92 ck	72.7				78.2	185 ck	82.0				78.2
48	83.0	78.8	+ 4.2	+ 5.33	82.4	91	74.5	72.7	+ 1.8	+ 2.48	80.1	186	65.6	82.0	—16.4	—20.00	62.6
49	79.7	82.5	— 2.8	— 3.39	75.5	90	73.1	71.3	+ 1.8	+ 2.52	80.2	187	71.3	64.7	+ 6.6	—10.20	70.2
50 ck	82.5				78.2	89 ck	71.3				78.2	188 ck	64.7				78.2
51	85.3	82.5	+ 2.8	+ 3.39	80.8	88	67.0	71.3	— 4.3	— 6.03	73.5	189	70.3	64.7	+ 5.6	+ 8.66	85.0
52	83.9	83.4	+ 0.5	+ 0.60	78.7	87	67.0	80.2	—13.2	—16.46	65.3	190	68.4	75.9	— 7.5	— 9.88	70.5
53 ck	83.4				78.2	86 ck	80.2				78.2	191 ck	75.9				78.2
54	81.6	83.4	— 1.8	— 2.16	76.5	85	70.3	80.2	— 9.9	—12.34	68.6	192	79.2	75.9	+ 3.3	+ 4.35	81.6
55	75.0	75.0	0.0	0.0	78.2	84	77.3	73.6	+ 3.7	+ 5.03	82.1	193	69.4	73.1	— 3.7	— 5.06	74.2
56 ck	75.0				78.2	83 ck	73.6				78.2	194 ck	73.1				78.2
57	83.4	75.0	+ 8.4	+11.20	87.0	82	81.1	73.6	+ 7.5	+10.19	86.2	195	67.0	73.1	— 6.1	— 8.34	71.7
58	85.3	76.4	+ 8.9	+11.65	87.3	81	73.6	75.0	— 1.4	— 1.87	76.7	196	82.5	71.3	+11.2	+15.71	90.5
59 ck	76.4				78.2	80 ck	75.0				78.2	197 ck	71.3				78.2
60	69.4	76.4	— 7.0	— 9.16	71.0	79	78.8	75.0	+ 3.8	+ 5.07	82.2	198	71.3	71.3			78.2
61	81.6	78.3	+ 3.3	+ 4.21	81.5	78	79.2	81.1	— 1.9	— 2.34	76.4	199	56.7	57.7	— 1.0	— 1.73	76.8
62 ck	78.3				78.2	77 ck	81.1				78.2	200 ck	57.7				78.2
63	79.7	78.3	+ 1.4	+ 1.79	79.6	76	92.8	81.1	+11.7	+14.43	89.5	201	63.8	57.7	+ 6.1	+10.57	86.5
64	80.6	79.2	+ 1.4	+ 1.77	79.6	75	79.2	84.8	— 5.6	— 6.60	73.0	202	66.6	70.3	— 3.7	— 5.26	74.1
65 ck	79.2				78.2	74 ck	84.8				78.2	203 ck	70.3				78.2
66	76.9	79.2	— 2.3	— 2.90	75.9	73	82.5	84.8	— 2.3	— 2.71	76.1	204	68.4	70.3	— 1.9	— 2.70	76.1
67	76.9	83.0	— 6.1	— 7.35	72.5	72	88.1	85.3	+ 2.8	+ 3.28	80.8	205	79.8	78.8	+ 1.0	+ 1.27	79.2
68 ck	83.0				78.2	71 ck	85.3				78.2	206 ck	78.8				78.2
69	73.6	83.0	— 9.4	—11.32	69.3	70	78.8	85.3	— 6.5	— 7.62	72.2	207	75.0	78.8	— 3.8	— 4.82	74.4

*The plats are arranged in this table in the same relative position as they occurred in the field.

TABLE 29—*Two hundred and seven thirtieth-acre Kherson oats plats calculated to show the progressive method of correction of yields by check plats where several plats intervene between checks*

Plat No.	Yield per acre		Deviation from normal		Corrected yield
	Actual	Normal			
	Bus.	*Bus.*	*Bushels*	*Per cent*	*Bushels*
1	75.5				
2 ck	84.8				78.2
3	86.3	84.8	+ 1.5	+ 1.77	79.6
4	84.4	84.8	— 0.4	— 0.47	77.8
5 ck	84.8				78.2
6	85.3	84.8	+ 0.5	+ 0.59	78.7
7	81.6	84.8	— 3.2	— 3.77	75.3
8 ck	84.8				78.2
9	80.2	83.0	— 2.8	— 3.37	75.6
10	79.7	81.1	— 1.4	— 1.73	76.9
11 ck	79.2				78.2
12	83.0	81.6	+ 1.4	+ 1.72	79.5
13	80.2	84.0	— 3.8	— 4.52	74.7
14 ck	86.3				78.2
15	81.1	82.7	— 1.6	— 1.93	76.7
16	77.8	79.1	— 1.3	— 1.64	76.9
17 ck	75.5				78.2
18	68.4	77.2	— 8.8	—11.40	69.3
19	78.8	78.9	— .1	— 0.13	78.1
20 ck	80.6				78.2
21	82.5	80.0	+ 2.5	+ 3.13	80.6
22	85.3	79.4	+ 5.9	+ 7.43	84.0
23 ck	78.8				78.2
24	80.2	81.1	— 0.9	— 1.11	77.3
25	78.8	83.4	— 4.6	— 5.52	73.9
26 ck	85.8				78.2
27	64.7	82.9	—18.2	—21.96	61.0
28	88.1	79.9	+ 8.2	+10.26	86.2
29 ck	76.9				78.2
30	83.4	77.8	+ 5.6	+ 7.20	83.8
31	80.6	78.7	+ 1.9	+ 2.41	80.1
32 ck	79.7				78.2
33	83.4	80.6	+ 2.8	+ 3.47	80.9

Plat No.	Yield per acre		Deviation from normal		Corrected yield
	Actual	Normal			
	Bus.	*Bus.*	*Bushels*	*Per cent*	*Bushels*
138	87.2				
137 ck	89.1				78.2
136	84.8	88.4	— 3.6	— 4.07	75.0
135	84.4	87.8	— 3.4	— 3.87	75.2
134 ck	87.2				78.2
133	82.0	85.4	— 3.4	— 3.98	75.1
132	85.3	83.7	+ 1.6	+ 1.91	79.7
131 ck	82.0				78.2
130	77.3	81.4	— 4.1	— 5.04	74.3
129	79.8	80.8	— 1.0	— 1.24	77.2
128 ck	80.2				78.2
127	82.2	77.0	+ 5.2	+ 6.75	83.5
126	64.7	73.9	— 9.2	—12.45	68.5
125 ck	70.8				78.2
124	79.2	72.4	+ 6.8	+ 9.39	85.5
123	77.8	74.0	+ 3.8	+ 5.14	82.2
122 ck	75.5				78.2
121	88.1	79.9	+ 8.2	+10.26	86.2
120	87.7	84.3	+ 3.4	+ 4.03	81.3
119 ck	88.6				78.2
118	81.6	86.4	— 4.8	— 5.56	73.8
117	85.3	84.2	+ 1.1	+ 1.31	79.2
116 ck	82.0				78.2
115	75.0	84.4	— 9.4	—11.14	69.5
114	75.9	86.8	—10.9	—12.56	68.4
113 ck	89.1				78.2
112	84.4	88.7	— 4.3	— 4.85	74.4
111	86.3	88.4	— 2.1	— 2.38	76.3
110 ck	88.1				78.2
109	79.2	87.7	— 8.5	— 9.69	70.6
108	80.6	87.2	— 6.6	— 7.57	72.3
107 ck	86.7				78.2
106	81.6	85.0	— 3.4	— 4.00	75.1

Plat No.	Yield per acre		Deviation from normal		Corrected yield
	Actual	Normal			
	Bus.	*Bus.*	*Bushels*	*Per cent*	*Bushels*
139	81.6				
140 ck	83.0				78.2
141	83.9	81.1	+ 2.8	+ 3.45	80.9
142	75.5	79.2	— 3.7	— 4.67	74.5
143 ck	77.3				78.2
144	76.9	78.9	— 2.0	— 2.53	76.2
145	76.9	80.5	— 3.6	— 4.47	74.7
146 ck	82.0				78.2
147	75.0	79.9	— 4.4	— 5.51	73.9
148	75.5	77.7	— 2.2	— 2.83	76.0
149 ck	75.5				78.2
150	74.1	74.3	— 0.2	— .27	78.0
151	69.8	73.0	— 3.2	— 4.38	74.8
152 ck	71.7				78.2
153	77.8	72.0	+ 5.8	+ 8.06	84.5
154	75.9	72.3	+ 3.6	+ 4.98	82.1
155 ck	72.7				78.2
156	73.1	74.7	— 1.6	— 2.14	76.5
157	75.0	76.7	— 1.7	— 2.22	76.5
158 ck	78.8				78.2
159	76.9	77.9	— 1.0	— 1.28	77.2
160	72.7	76.9	— 4.2	— 5.46	73.9
161 ck	75.9				78.2
162	75.9	76.9	— 1.0	— 1.30	77.2
163	80.6	77.9	+ 2.7	+ 3.47	80.9
164 ck	78.8				78.2
165	75.9	76.3	— 0.4	— 0.52	77.8
166	75.5	73.8	+ 1.7	+ 2.30	80.0
167 ck	71.3				78.2
168	72.2	71.6	+ 0.6	+ 0.84	78.9
169	72.7	71.9	+ 0.8	+ 1.11	79.1
170 ck	72.2				78.2
171	77.3	74.4	+ 2.9	+ 3.90	81.3

34	81.1	81.5	— 0.4	— 0.49	77.8	105	82.0	83.3	— 1.3	— 1.56	77.0	172	78.3	76.6	+ 1.7	+ 2.22	79.9
35 ck	82.5				78.2	104 ck	81.6				78.2	173 ck	78.8				78.2
36	80.2	82.2	— 2.0	— 2.43	76.3	103	89.5	78.1	+11.4	+14.60	89.6	174	75.9	79.4	— 3.5	— 4.41	74.7
37	79.7	81.9	— 2.2	— 2.69	76.1	102	75.9	74.7	— 1.2	— 1.61	76.9	175	78.8	80.0	— 1.2	— 1.50	77.0
38 ck	81.6				78.2	101 ck	71.3				78.2	176 ck	80.6				78.2
39	83.4	83.3	+ 0.1	+ 0.12	78.3	100	73.6	70.5	+ 3.1	+ 4.40	81.6	177	70.8	79.9	— 9.1	—11.39	69.3
40	78.8	85.0	— 6.2	— 7.29	72.5	99	83.0	69.7	+13.3	+19.08	93.1	178	72.7	79.1	— 6.4	— 8.09	71.9
41 ck	86.7				78.2	98 ck	68.9				78.2	179 ck	78.3				78.2
42	82.5	84.0	— 1.5	— 1.79	76.8	97	73.6	71.6	+ 2.0	+ 2.79	80.4	180	77.3	76.9	+ 0.4	+ 0.52	78.6
43	85.8	81.4	+ 4.4	+ 5.41	82.4	96	84.4	74.3	+10.1	+13.59	88.8	181	81.6	75.5	+ 6.1	+ 8.09	84.5
44 ck	78.8				78.2	95 ck	76.9				78.2	182 ck	71.4				78.2
45	79.7	78.8	+ 0.9	+ 1.14	79.1	94	82.0	75.5	+ 6.5	+ 8.61	84.9	183	75.5	76.7	— 1.2	— 1.56	77.0
46	69.4	78.8	— 9.4	—11.93	68.9	93	71.7	74.1	— 2.4	— 3.24	75.7	184	72.7	79.3	— 6.6	— 8.32	71.7
47 ck	78.8				78.2	92 ck	72.7				78.2	185 ck	82.0				78.2
48	83.0	80.0	+ 3.0	+ 3.75	81.1	91	74.5	72.3	+ 2.3	+ 3.04	80.6	186	65.6	76.3	—10.7	—14.02	67.2
49	79.7	81.2	— 1.5	— 1.85	76.8	90	73.1	71.8	+ 1.3	+ 1.81	79.6	187	71.3	70.5	+ 0.8	+ 1.13	79.1
50 ck	82.5				78.2	89 ck	71.3				78.2	188 ck	64.7				78.2
51	85.3	82.8	+ 2.5	+ 3.02	80.6	88	67.0	74.3	— 7.3	— 9.82	70.5	189	70.3	68.4	+ 1.9	+ 2.78	80.4
52	83.9	83.1	+ 0.8	+ .96	78.9	87	67.0	77.3	—10.3	—13.32	67.8	190	68.4	72.1	— 3.7	— 5.13	74.2
53 ck	83.4				78.2	86 ck	80.2				78.2	191 ck	75.9				78.2
54	81.6	80.6	+ 1.0	+ 1.24	79.2	85	70.3	78.0	— 7.7	— 9.87	70.5	192	79.2	74.9	+ 4.3	+ 5.74	82.7
55	75.0	77.8	— 2.8	— 3.60	75.4	84	77.3	75.8	+ 1.5	+ 1.98	79.7	193	69.4	74.0	— 4.6	— 6.22	73.3
56 ck	75.0				78.2	83 ck	73.6				78.2	194 ck	73.1				78.2
57	83.4	75.5	+ 7.9	+10.46	86.4	82	81.1	74.1	+ 7.0	+ 9.45	85.6	195	67.0	72.5	— 5.5	— 7.59	72.3
58	85.3	76.0	+ 9.3	+12.24	87.8	81	73.6	74.6	— 1.0	— 1.34	77.2	196	82.5	71.9	+10.6	+14.74	89.7
59 ck	76.4				78.2	80 ck	75.0				78.2	197 ck	71.3				78.2
60	69.4	77.0	— 7.6	— 9.87	70.5	79	78.8	77.0	+ 1.8	+ 2.34	80.0	198	71.3	66.7	+ 4.6	+ 6.90	72.8
61	81.6	77.6	+ 4.0	+ 5.15	82.2	78	79.2	79.0	+ 0.2	+ 0.25	78.4	199	56.7	62.2	— 5.5	— 8.84	71.3
62 ck	78.3				78.2	77 ck	81.1				78.2	200 ck	57.7				78.2
63	79.7	78.6	+ 1.1	+ 1.40	79.3	76	92.8	82.3	+10.5	+12.76	88.2	201	63.8	61.9	+ 1.9	+ 3.07	80.6
64	80.6	78.9	+ 0.7	+ .89	78.9	75	79.2	83.5	— 4.3	— 5.15	74.2	202	66.6	66.1	+ .5	+ 0.76	78.8
65 ck	79.2				78.2	74 ck	84.8				78.2	203 ck	70.3				78.2
66	76.9	80.5	— 3.6	— 4.47	74.7	73	82.5	85.0	— 2.5	— 2.94	75.9	204	68.4	73.1	— 4.7	— 6.43	73.2
67	76.9	81.8	— 4.9	— 5.99	73.5	72	88.1	85.2	— 2.9	— 3.40	75.5	205	79.8	75.9	+ 3.9	+ 5.14	82.2
68 ck	83.0				78.2	71 ck	85.3				78.2	206 ck	78.8				78.2
69	73.6					70	78.8					207	75.0				

*The plats are arranged in this table in the same relative position as they occurred in the field.

The three foregoing tables (27-29) show the exact arrangement in which the 207 Kherson oats plats were grown in the field. Certain plats have been designated as check plats according to each of the above three methods, and the intervening plats have been treated as test plats. The test plats have been corrected in yield according to the check plats. If such correction had been effective, the coefficient of variability for the corrected yields would have been materially reduced below the coefficient of variability for the actual yields. On the contrary, however, the coefficients of variability were reduced less than 1 per cent, being 7.8 per cent for the actual yields and 7.0 per cent for the corrected yields, as an average for the three methods of correction.

Table 30 gives the coefficients of variability for the actual and corrected yields of the test plats indicated in Tables 27, 28, and 29.

TABLE 30—*Effect upon yield from correcting thirtieth-acre Kherson oats field plats according to various accepted means of check plat correction* (1916)*

Arrangement of check plats used for correction	Frequency	Intervening plat yields		Standard deviation from mean for		Coefficient of variability for	
		Actual yields	Corrected yields	Actual yields	Corrected yields	Actual yields	Corrected yields
		Bushels	*Bushels*	*Bushels*	*Bushels*	*Per cent*	*Per cent*
Alternate check plats. Correction based upon average of two adjacent checks	102	78.2	78.1	6.14	5.47	7.85	7.01
Checks every third plat. Correction based upon one adjacent check plat. . . .	138	78.0	77.7	6.08	5.71	7.79	7.35
Checks every third plat. Correction by progressive method based upon two nearest checks. .	132	78.0	77.7	6.13	5.10	7.87	6.57

*Calculated from data in Tables 27, 28, and 29.

REDUCTION OF ERROR BY REPLICATION

The actual yields from the first 200 of these similarly treated plats of Kherson oats, described on pages 52 to 60, have been compiled to show the extreme variations, average and standard deviations from the mean, and the coefficients of variability for single plats and for the mean yields of two, four, and eight plats averaged together. These groupings have been arranged for both adjacent and systematically distributed plats. The results are given in Table 31.

It is clearly shown that replication greatly reduces the extreme variation and coefficient of variability in the yield of field plats. A given number of replications are also much more effective when systematically distributed than when adjacent plats are averaged.

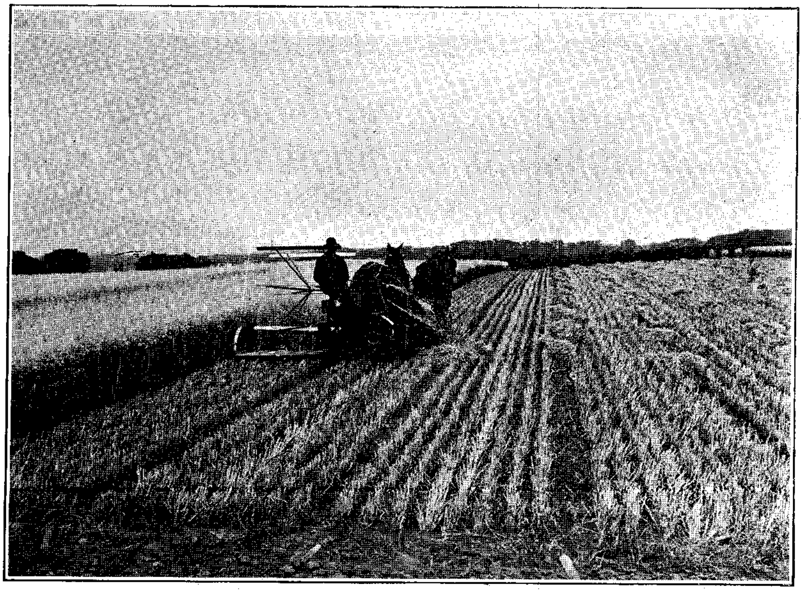


Fig. 15—Harvesting thirtieth-acre plats of Kherson oats. The binder has a gasoline engine attached which cuts and binds the grain. This facilitates cleaning out the binder quickly at the end of each plat. Note the narrow bare spaces between plats. If the plats are tangled by lodging, they are separated by hand before being cut. This shape of plat is very convenient, since it is one drill in width and may be harvested by one swath of the binder

TABLE 31—*Variation in yield of two hundred thirtieth-acre Kherson oats test plats when grouped in various numbers of systematically distributed or adjacent plats (1916)*

Classification	Number of groups	Mean yield per acre	Extreme variation	Average deviation	Standard deviation	Coefficient of variability
		Bushels	*Bushels*	*Bushels*	*Bushels*	*Per cent*
GROUP COMPOSED OF SYSTEMATICALLY DISTRIBUTED PLATS						
Two hundred single plats	a 25	80.96	68.4—86.3	3.10	4.03	4.97
	b 25	80.67	64.7—88.1	3.29	4.87	6.04
	25	80.29	69.4—88.1	3.60	4.34	5.41
	d 25	76.10	67.0—92.8	4.77	5.86	7.71
	e 25	81.80	70.8—89.5	4.54	5.49	6.72
	f 25	80.10	64.7—89.1	4.24	5.25	6.55
	g 25	75.40	69.8—80.6	2.43	2.86	3.79
	h 25	72.40	56.7—82.5	5.15	6.66	9.21
Average	....	78.5	66.4—87.1	3.44	4.92	6.30
Every 100th plat, two plats in a group	a 25	81.4	73.4—87.9	2.82	3.44	4.23
	b 25	80.4	73.5—85.3	2.79	3.19	3.96
	c 25	77.9	71.1—83.2	2.38	2.94	3.77
	d 25	74.3	65.7—86.7	3.75	4.77	6.41
Average	....	78.5	70.9—85.8	2.93	3.58	4.59
Every 50th plat, four plats in a group	a 25	79.6	75.5—84.3	1.83	2.20	2.76
	b 25	77.3	72.0—81.0	2.04	2.37	3.06
Average	....	78.5	73.8—82.7	1.99	2.28	2.91
Every 25th plat, eight plats in a group	25	78.5	74.4—82.2	1.24	1.67	2.13

TABLE 31–*(Continued)–Variation in yield of two hundred thirtieth-acre Kherson oats test plats when grouped in various numbers of systematically distributed and adjacent plats (1916)*

Classification	Number of groups	Mean yield per acre	Extreme variation	Average deviation	Standard deviation	Coefficient of variability
		Bushels	*Bushels*	*Bushels*	*Bushels*	*Per cent*
GROUP COMPOSED OF ADJACENT PLATS						
Four adjacent plats in a group	a 25	80.8	72.0—85.4	2.10	2.99	3.71
	b 25	78.2	67.0—86.7	3.89	4.79	6.13
	c 25	81.0	67.8—88.2	3.70	4.65	5.74
	d 25	73.9	57.2—79.7	3.38	4.27	6.26
Average	....	78.5	66.0—85.0	3.26	4.18	5.46
Two adjacent plats in a group	a 25	79.5	72.9—84.8	2.60	3.30	4.15
	b 25	77.4	64.3—85.8	3.98	4.96	6.41
Average	....	78.5	68.6—85.3	3.29	4.13	5.28
Eight adjacent plats in a group	25	78.5	68.6—83.6	3.16	3.75	4.78
207 PLATS GROUPED TO MAKE PLATS OF VARIOUS SHAPES AND SIZES						
Three plats grouped lengthwise to make a plat	a 23	79.8	71.6—85.6	2.52	3.20	4.01
	b 23	78.9	71.3—84.6	2.17	2.90	3.67
	c 23	76.1	72.4—82.4	2.50	2.93	3.85
Average	....	78.3	71.8—84.2	2.40	3.01	3.84
Three plats grouped sidewise to make a plat	a 23	80.4	73.9—84.8	2.14	2.59	3.22
	b 23	79.9	70.5—86.0	4.31	4.96	6.21
	c 23	74.4	59.4—82.8	3.13	4.54	6.11
Average	....	78.2	67.9—84.5	3.19	4.03	5.18
Nine plats grouped lengthwise (3x3 plats) to make a plat*	a 23	78.2	73.8—84.0	2.27	2.62	3.35
Nine plats grouped sidewise (1x9 plats) to make a plat	a 23	78.2	68.6—83.1	3.23	3.78	4.84

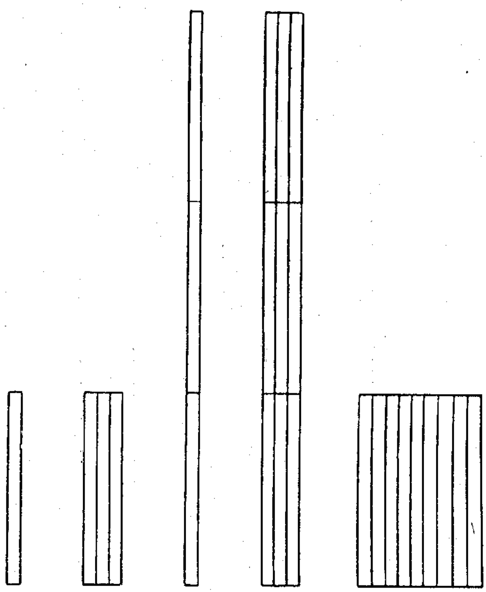
*In this grouping the combined plat was three plats long and three plats wide.

The yield of the 200 individual plats varied from 56.7 to 92.8 bushels per acre. The mean for eight groups of 25 single plats each gives an extreme difference between single plats of 20.7 bushels per acre. When two, four, and eight systematically distributed plats are averaged, the extreme differences in yield are respectively 14.9, 8.9, and 7.8 bushels. When two, four, and eight adjacent plats are averaged, these extreme differences are 19, 16.7, and 15 bushels. For systematically distributed plats the coefficients of variability for one, two, four, and eight plats in a group are 6.30, 4.59, 2.91, and 2.13 per cent. For adjacent plats the coefficients of variability for one, two, four, and eight plats in a group are 6.30, 5.46, 5.28, and 4.78 per cent.

Systematic distribution of replicated plats is seen to be very effective in reducing experimental error due to environmental variations.

EFFECT OF SHAPE AND SIZE OF PLAT

The 207 thirtieth-acre Kherson oats plats described in the preceding discussion were grouped to enable a compari-



Various ways of combining plats to make plats of different sizes and shapes (Table 31) son of long narrow plats with short wide plats. The groupings illustrated in the following diagrams were compared. (In the 1 x 9 grouping, three groups were necessarily irregular in shape since 9 is not a multiple of 69.)

The results are included in Table 31. Long, narrow plats are indicated to be more reliable than short wide plats of the same area. Increasing the size of the plat is less effective in overcoming experimental error than the systematic distribution of plats equal in combined area.

SIGNIFICANCE OF THE "PROBABLE ERROR"

The "probable error" calculation is being used somewhat by field crop experimenters. Its use is rather inviting since a small "probable error" is customarily regarded as indicating accuracy in the results. Davenport's interpretation is generally accepted, namely: "It (the probable error) indicates the degree of confidence which we should place in results obtained by statistical methods."

Where plats are replicated two or more times, the probable error of the mean is based upon the standard deviation, and is determined by the following formula:

$$\text{Probable error of mean} = \pm\, 0.6745 \frac{\text{standard deviation}}{\sqrt{\text{number of variates}}}$$

which is also stated $E_m = \pm\, 0.6745 \frac{\sigma}{\sqrt{n}}$

The probable error is regarded as an upper and lower limit of divergence for which the chance is even that the true mean does not lie outside of these limits. Commenting upon the likelihood of the true mean lying outside of the limits set by the probable error, Davenport (1907) states:

"Of course the error in a determination has also an even chance of lying outside the limits set by the probable error (E), but the following table will show that it is very unlikely that the error is many times as great as E. Thus the chances that the true value lies within the range set by ± E, ± 2E, etc., are as follows:

± E the chances are even
±2 E the chances are 4.5 to 1
±3 E the chances are 21 to 1
±4 E the chances are 142 to 1
±5 E the chances are 1310 to 1
±6 E the chances are 19,200 to 1
±7 E the chances are 420,000 to 1
±8 E the chances are 17,000,000 to 1
±9 E the chances are about 1,000,000,000 to 1

"It is extremely improbable, therefore, that an error will be many times as large as the probable error. For instance, it is practically certain that the error is not as large as 9 E, since the table shows that the chances are about a billion to one in favor of its being smaller than 9 E.

"Thus by giving, along with any result, the calculated probable error, the reader may know what degree of confidence is to be placed in the results."

In common usage, it is stated that the actual difference in the yield of two plats must be three times the probable error before the difference in yield is significant.

It should be agreed at the outset that the probable error of a mean yield has significance only when the variations entering into the mean are purely accidental rather than systematic. This distinction is understood by biometricians who universally attach importance to the probable error calculation when used in a legitimate manner. There appear to be strong possibilities of misusing the probable error and overestimating its value in agronomic studies. This need not be regarded as any defect in the probable error formula, but rather as a misapplication thereof to experimental results possessing either visible or invisible systematic errors.

Field crop investigators consider it good technique to replicate test plats. It has been proposed that, in such tests, small probable errors for the mean yields of the various varieties or treatments would indicate reliability and justify confidence in the comparative yields.

For the purpose of studying the significance of the probable error in field crop tests, the first 200 consecutive thirtieth-acre Kherson oats plats described on pp. 52 to 64 have been grouped in 50 sets of four adjacent plats and also 50 sets of four systematically distributed plats, and the probable error calculated for the mean yield of each group of four plats.

PROBABLE ERROR FOR FIFTY GROUPS OF FOUR ADJACENT THIRTIETH-ACRE PLATS OF KHERSON OATS

That the probable error cannot apply to the mean yields of adjacent duplicate plats in a variety test is brought out by the following data:

In Table 32 are given the mean yields for 50 groups of four adjacent plats, together with the average deviation, standard deviation, and probable error for each group. The average deviation of each group from the mean yield for the entire 200 plats is also indicated and in the last column of the table is given the ratio of this deviation to the probable error.

If it is permissible to assume that one group of four duplicate plats is comparable with another group of four plats in the same field, then it would also seem permissible to assume that in the present instances, the mean yield for the entire 200 similarly treated oats plats should represent the correct yield or true value of any or all of the individual groups within the field. If this assumption be made with the adjacent duplicate plats (Table 32), the actual error of these group means exceeded their probable error approximately 0, 1, 2, 3, 4, 5, 6, 7, 8, 10, 11, and 15 times respectively in 9, 5, 7, 7, 8, 4, 4, 1, 2, 1, 1, and 1 groups. (See Col. 11, Table 32). This is very inconsistent with the table of probabilities quoted from Davenport on page 66, and shows that a uniform appearing field may be so heterogeneous in soil conditions that its mean yield cannot be regarded as correctly representing the true value of its various parts.

Since all the plats were treated and planted alike any difference in the yields of the groups represents experimental error, either in mechanical operations or in soil variation.

Among the 50 groups of adjacent plats, one group yielded 14.2 bushels less and another group 7.3 bushels more per acre than the 200-plat mean. These extremes represent an experimental error of 21.5 bushels since both should have yielded alike if the method of comparison were reliable.

Should we presume that groups No. 30 and No. 50 (Table 32) are distinct varieties in a comparative variety test, we would have a difference in yield of 21.5 bushels per acre. After multiplying the probable error of each mean by three, there remains a net difference of 11.63 bushels between the probable error ranges. Placing confidence in the probable error calculation, we would believe that there is a difference

TABLE 32—*Probable error for mean yields of four adjacent thirtieth-acre Kherson oats plats when 200 plats are arranged in 50 groups (1916)*

Group No.	Yield per acre for four plats averaged				Mean yield per acre	Average deviation	Standard deviation	Probable error of mean	Deviation of group mean from field mean*	Ratio of Col. 10 to Col. 9
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	
1	75.5	84.8	86.3	84.4	82.8	3.600	4.246	±1.43	+ 4.3	3.01
2	84.8	85.3	81.6	84.8	84.1	1.275	1.472	± .50	+ 5.6	11.20
3	80.2	79.7	79.2	83.0	80.5	1.225	1.555	± .52	+ 2.0	3.85
4	80.2	86.3	81.1	77.8	81.4	2.500	3.102	±1.05	+ 2.9	2.76
5	75.5	68.4	78.8	80.6	75.8	3.875	4.661	±1.57	— 2.7	1.72
6	82.5	85.3	78.8	80.2	81.7	2.200	2.463	± .83	+ 3.2	3.86
7	78.8	85.8	64.7	88.1	79.4	7.600	9.126	±3.08	+ 0.9	0.29
8	76.9	83.4	80.6	79.7	80.2	1.850	2.321	± .78	+ 1.7	2.18
9	83.4	81.1	82.5	80.2	81.8	1.150	1.235	± .51	+ 3.3	6.47
10	79.7	81.6	83.4	78.8	80.9	1.625	1.774	± .60	+ 2.4	4.00
11	86.7	82.5	85.8	78.8	83.5	2.800	3.107	±1.05	+ 5.0	4.76
12	79.7	69.4	78.8	83.0	77.7	4.175	5.054	±1.70	— 0.8	0.47
13	79.7	82.5	85.3	83.9	82.9	1.750	2.071	± .70	+ 4.4	6.29
14	83.4	81.6	75.0	75.0	78.8	3.750	3.804	±1.28	+ 0.3	0.23
15	83.4	85.3	76.4	69.4	78.6	5.725	6.273	±2.12	+ 0.1	0.05
16	81.6	78.3	79.7	80.6	80.1	1.050	1.215	± .41	+ 1.6	3.90
17	79.2	76.9	76.9	83.0	79.0	2.100	2.493	± .84	+ 0.5	0.60
18	73.6	78.8	85.3	88.1	81.5	5.250	5.650	±1.91	+ 3.0	1.57
19	82.5	84.8	79.2	92.8	84.8	3.975	5.016	±1.69	+ 6.3	3.73
20	81.1	79.2	78.8	75.0	78.5	1.775	2.213	± .75	....	....
21	73.6	81.1	73.6	77.3	76.4	2.800	3.106	±1.05	— 2.1	2.00
22	70.3	80.2	67.0	67.0	71.1	4.525	5.410	±1.82	— 7.4	4.07
23	71.3	73.1	74.5	72.7	72.9	.900	1.140	± .38	— 5.6	14.73
24	71.7	82.0	76.9	84.4	78.8	4.450	4.890	±1.65	+ 0.3	0.18
25	73.6	68.9	83.0	73.6	74.8	4.125	5.122	±1.73	— 3.7	2.14

*The field mean equals the mean for the entire 200 plats reported in this table.

TABLE 32.—*(Continued)—Probable error for mean yields of four adjacent thirtieth-acre Kherson oats plats when 200 plats are arranged in 50 groups (1916)*

Group No.	Yield per acre for four plats averaged				Mean yield per acre	Average deviation	Standard deviation	Probable error of mean	Deviation of group mean from field mean*	Ratio of Col. 10 to Col. 9
(1)	(2) *Bushels*	(3) *Bushels*	(4) *Bushels*	(5) *Bushels*	(6) *Bushels*	(7) *Bushels*	(8) *Bushels*	(9) *Bushels*	(10) *Bushels*	(11)
26	71.3	75.9	89.5	81.6	79.6	5.975	6.793	±2.29	+ 1.1	0.48
27	82.0	81.6	86.7	80.6	82.7	1.975	2.351	± .79	+ 4.2	5.32
28	79.2	88.1	86.3	84.4	84.5	2.700	3.328	±1.12	+ 6.0	5.36
29	89.1	75.9	75.0	82.0	80.5	5.050	5.648	±1.90	+ 2.0	1.05
30	85.3	81.6	88.6	87.7	85.8	2.350	2.710	± .91	+ 7.3	8.02
31	88.1	75.5	77.8	79.2	80.2	4.000	4.777	±1.61	+ 1.7	1.06
32	70.8	64.7	82.2	80.2	74.5	6.725	7.098	±2.39	— 4.0	1.67
33	79.8	77.3	82.0	85.3	81.1	2.550	2.940	± .99	+ 2.6	2.63
34	82.0	87.2	84.4	84.8	84.6	1.400	1.844	± .62	+ 6.1	9.84
35	89.1	87.2	81.6	83.0	85.2	2.925	3.042	±1.03	+ 6.7	6.50
36	83.9	75.5	77.3	76.9	78.4	2.750	3.245	±1.09	— 0.1	0.09
37	76.9	82.0	75.0	75.5	77.4	2.350	2.774	± .94	— 1.1	1.17
38	75.5	74.1	69.8	71.7	72.8	2.025	2.190	± .74	— 5.7	7.70
39	77.8	75.9	72.7	73.1	74.9	1.975	2.091	± .70	— 3.6	5.14
40	75.0	78.8	76.9	72.7	75.9	2.000	2.262	± .76	— 2.6	3.42
41	75.9	75.9	80.6	78.8	77.8	1.900	2.004	± .68	— 0.7	1.03
42	75.9	75.5	71.3	72.2	73.7	1.975	2.006	± .68	— 4.8	7.06
43	72.7	72.2	77.3	78.3	75.1	2.675	2.704	± .91	— 3.4	3.74
44	78.8	75.9	78.8	80.6	78.6	1.275	1.686	± .57	+ 0.1	0.18
45	70.8	72.7	78.3	77.3	74.8	3.025	3.119	±1.05	— 3.7	3.52
46	81.6	74.1	75.5	72.7	76.0	2.825	3.395	±1.14	— 2.5	2.19
47	82.0	65.6	71.3	64.7	70.9	5.750	6.890	±2.32	— 7.6	3.28
48	70.3	68.4	75.9	79.2	73.5	4.100	4.316	±1.46	— 5.0	3.42
49	69.4	73.1	67.0	82.5	73.0	4.800	5.900	±1.99	— 5.5	2.76
50	71.3	71.3	56.7	57.7	64.3	7.050	7.059	±2.38	—14.2	5.97

*The field mean equals the mean for the entire 200 plats reported in this table.

TABLE 33—*Probable error for mean yields of four systematically distributed thirtieth-acre Kherson oats plats when 200 plats are arranged in 50 groups (1916)*

Group No.	Yield per acre for four plats averaged				Mean yield per acre	Average deviation	Standard deviation	Probable error of mean	Deviation of group mean from field mean*	Ratio of Col. 10 to Col. 9
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	
1	75.5	85.3	71.3	69.8	75.5	4.925	6.045	±2.04	—3.0	1.47
2	84.8	83.9	75.9	71.7	79.1	5.275	5.490	±1.85	+0.6	0.32
3	86.3	83.4	89.5	77.8	84.3	3.650	4.304	±1.45	+5.8	4.00
4	84.4	81.6	81.6	75.9	80.9	2.475	3.091	±1.04	+2.4	2.31
5	84.8	75.0	82.0	72.7	78.6	4.775	4.944	±1.67	+0.1	0.06
6	85.3	75.0	81.6	73.1	78.8	4.700	4.925	±1.66	+0.3	0.18
7	81.6	83.4	86.7	75.0	81.7	3.375	4.266	±1.44	+3.2	2.22
8	84.8	85.3	80.6	78.8	82.4	2.675	2.756	± .93	+3.9	4.19
9	80.2	76.4	79.2	76.9	78.2	1.525	1.576	± .53	—0.3	0.57
10	79.7	69.4	88.1	72.7	77.5	6.425	7.174	±2.42	—1.0	0.41
11	79.2	81.6	86.3	75.9	80.8	3.200	3.790	±1.28	+2.3	1.80
12	83.0	78.3	84.4	75.9	80.4	3.300	3.443	±1.16	+1.9	1.64
13	80.2	79.7	89.1	80.6	82.4	3.350	3.881	±1.31	+3.9	2.98
14	86.3	80.6	75.9	78.8	80.4	3.050	3.797	±1.28	+1.9	1.48
15	81.1	79.2	75.0	75.9	77.8	2.350	2.465	± .83	—0.7	0.84
16	77.8	76.9	82.0	75.5	78.1	2.000	2.424	± .82	—0.4	0.49
17	75.5	76.9	85.3	71.3	77.3	4.050	5.084	±1.71	—1.2	0.70
18	68.4	83.0	81.6	72.2	76.3	6.000	6.168	±2.08	—2.2	1.06
19	78.8	73.6	88.6	72.7	78.4	5.275	6.319	±2.13	—0.1	0.05
20	80.6	78.8	87.7	72.2	79.8	4.325	5.518	±1.86	+1.3	0.70
21	82.5	85.3	88.1	77.3	83.3	3.400	3.990	±1.35	+4.8	3.56
22	85.3	88.1	75.5	78.3	81.8	4.900	5.096	±1.72	+3.3	1.92
23	78.8	82.5	77.8	78.8	79.5	1.525	1.794	± .61	+1.0	1.64
24	80.2	84.8	79.2	75.9	80.0	2.475	3.183	±1.07	+1.5	1.40
25	78.8	79.2	70.8	78.8	76.9	3.050	3.526	±1.19	—1.6	1.34

*The field mean equals the mean for the entire 200 plats reported in this table.

TABLE 33—*(Continued)—Probable error for mean yields of four systematically distributed thirtieth-acre Kherson oats plats when 200 plats are arranged in 50 groups (1916)*

Group No.	Yield per acre for four plats averaged				Mean yield per acre	Average deviation	Standard deviation	Probable error of mean	Deviation of group mean from field mean*	Ratio of Col. 10 to Col. 9
(1)	(2) *Bushels*	(3) *Bushels*	(4) *Bushels*	(5) *Bushels*	(6) *Bushels*	(7) *Bushels*	(8) *Bushels*	(9) *Bushels*	(10) *Bushels*	(11)
26	85.8	92.8	64.7	80.6	81.0	8.325	10.364	±2.49	+2.5	1.00
27	64.7	81.1	82.2	70.8	74.7	6.950	7.287	±2.46	—3.8	1.54
28	88.1	79.2	80.2	72.7	80.1	4.100	5.468	±1.84	+1.6	0.87
29	76.9	78.8	79.8	78.3	78.5	.850	1.046	± .35	....	....
30	83.4	75.0	77.3	77.3	78.3	2.600	3.118	±1.05	—0.2	0.19
31	80.6	73.6	82.0	81.6	79.5	2.900	3.146	±1.15	+1.0	0.87
32	79.7	81.1	85.3	74.1	80.1	3.150	4.006	±1.35	+1.6	1.19
33	83.4	73.6	82.0	75.5	78.6	4.075	4.160	±1.40	+0.1	0.07
34	81.1	77.3	87.2	72.7	79.6	4.575	5.313	±1.79	+1.1	0.62
35	82.5	70.3	84.4	82.0	79.8	4.750	5.557	±1.87	+1.3	0.70
36	80.2	80.2	84.8	65.6	77.7	6.050	7.234	±2.44	—0.8	0.33
37	79.7	67.0	89.1	71.3	76.8	7.625	8.455	±2.85	—1.7	0.60
38	81.6	67.0	87.2	64.7	75.1	9.275	9.519	±3.21	—3.4	1.06
39	83.4	71.3	81.6	70.3	76.7	5.850	5.895	±1.99	—1.8	0.90
40	78.8	73.1	83.0	68.4	75.8	5.075	5.542	±1.87	—2.7	1.44
41	86.7	74.5	83.9	75.9	80.3	5.050	5.170	±1.74	+1.8	1.03
42	82.5	72.7	75.5	79.2	77.5	3.375	3.706	±1.25	—1.0	0.80
43	85.8	71.7	77.3	69.4	76.1	5.500	6.320	±2.13	—2.4	1.05
44	78.8	82.0	76.9	73.1	77.7	2.700	3.221	±1.09	—0.8	0.73
45	79.7	76.9	76.9	67.0	75.1	4.075	4.828	±1.63	—3.4	2.09
46	69.4	84.4	82.0	82.5	79.6	5.075	5.942	±2.00	+1.1	0.55
47	78.8	73.6	75.0	71.3	74.7	2.225	2.724	± .92	—3.8	4.13
48	83.0	68.9	75.5	71.3	74.7	4.575	5.356	±1.81	—3.8	2.10
49	79.7	83.0	75.5	56.7	73.7	8.525	10.183	±3.43	—4.8	1.40
50	82.5	73.6	74.1	57.7	72.0	7.125	8.968	±3.02	—6.5	2.15

*The field mean equals the mean for the entire 200 plats in this table.

of 11.63 bushels in the true value of the two varieties. However, we know in this case that both groups should have yielded alike since they were planted to the same crop. The probable error would give us confidence in very inaccurate results.

Slightly different results are obtained when the above example is calculated by the following prescribed formula: "The probable error of the difference of two means each affected with a probable error, is equal to the square root of the sum of the squares of the probable errors." By this formula the difference in mean yield of groups Nos. 30 and 50 equals 21.5 ± 2.55 bushels. Three times the probable error is 7.65 bushels which leaves a net difference of 13.85 bushels.

PROBABLE ERROR OF FIFTY GROUPS OF FOUR SYSTEMATICALLY DISTRIBUTED THIRTIETH-ACRE PLATS OF KHERSON OATS

Table 33 contains results with the same 200 Kherson Oats plats as compiled in Table 32, except that systematically distributed plats rather than adjacent plats are averaged in groups of four each. If the mean yield of the entire 200 plats is here regarded as the true value of the various group means, the actual error of these group means exceeded their probable error 0, 1, 2, 3, and 4 times in 10, 25, 10, 1, and 4 groups (See Col 11). This is a marked reduction in actual error as compared with similar data for adjacent plats and indicates a great advantage for systematic distribution. An application of the probable error to these systematically distributed plats would seem fairly reasonable altho it cannot be applied absolutely.

Because of chance groupings of either large or small variations where relatively small numbers are used, the actual error of a mean may be greater than three times its probable error, or it may be smaller than the probable error. Data may be either more or less accurate than an application of the probable error would indicate.

EXAMPLES OF LIMITATION OF THE PROBABLE ERROR

Small Grain Row Tests—In Tables 1 to 7 were given the relative small grain yields of rate-of-planting or variety tests in alternating nursery rows. The plats were replicated 50 times and the probable error of the mean yields is indicated. The yields in these plats were subject to two sources of error, namely soil variation and plat competition. Corresponding tests were also made in five-row plats relatively free from plat competition and subject primarily only to soil variations.

In Table 1 (1913) the yields of the thick and thin planted wheat rows were, respectively, 389±5.3 and 264±3.8 grams. Altho the probable error for each yield is less than 2 per cent, the actual error of the relative yields due to competition is 24.4 per cent. In 1914 the yields of the thick and thin planted wheat rows were respectively 327±6.66 and 115±3.6 grams. Altho the probable error for each yield is only 2 per cent, the actual error of the relative yields, due to competition, is 56.8 per cent.

In 1913 (Table 2) the probable errors for the mean yields of thick and thin planted oats rows were less than 2 per cent, but the actual error in relative yields, due to competition, was 20 per cent. In 1914 the probable errors for similar yields were also below 2 per cent, while the actual error in relative yields, due to competition, was 34.3 per cent.

Similar examples are seen in variety tests in Tables 3 to 7. We would have great confidence in these single-row tests were we to judge them by their low "probable errors." However, it is evident that this confidence would be badly misplaced.

Crop tests are subject to such a multitude of local environmental influences that errors in them cannot be regarded as occurring according to the formulas or rules of chance calculated from purely mechanical observations. The probable error calculation may apply, for example, to the chance drawing of black and white marbles from a bag at a given ratio to each other. But variations in crop yields are no such simple matter, and the probable error not only may have little significance but may be misleading.

Water Requirements of Corn and Wheat—As further illustration of the limitation of the probable error, the following simple data from our 1916 water requirements of crop studies may be cited.

The object was to make a comparative test of the relative water requirements for grain production of a standard variety of both corn and winter wheat. Potometers, 16 by 36 inches in size and containing 250 pounds of well-manured moisture-free soil, were used. (The method of testing is described in detail in Nebraska Research Bulletin No. 6.)

Previous experiments had indicated that these potometers would grow one corn plant in a normal manner. The ratio of 100 seeds of wheat to one of corn is normal in planting under field conditions in this region. Accordingly in comparing corn and wheat in potometers they were planted respectively at the rates of one plant and 100 plants per pot.

Under these conditions the respective water requirements for grain production of the corn and wheat were 743 ± 48 and 1017 ± 60. However, when the corn was grown at the rate of six plants per potometer these relative water requirements were 3481 ± 389 and 1017 ± 60.

Applying the general rule of "three times the probable error," we may be fairly confident from the one comparison that Hogue's Yellow Dent corn uses considerably less water than Turkey Red winter wheat, and from the other comparison we may be equally confident that corn uses more than double the amount of water for grain production than the wheat.

In the first comparison the degree of cropping for this quantity of soil corresponded well with normal field conditions for each crop. In the second test, however, the corn was planted relatively much too thick, and for this reason the ratio of grain to vegetative growth was greatly reduced. As a result the water requirement for grain production was increased.

EFFECT OF CHANGE IN METHODS ON AGRONOMIC EQUIPMENT

Replacing the single-row nursery test plat planted in duplicate with five-row test plats replicated 10 times increases the land requirement 25 times for such nursery testing. In testing hoed crops the substitution of three-row plats, replicated five times, for single duplicated rows requires 15 rows rather than two rows. The replication of small grain field plats five times, rather than twice, greatly increases the land requirement.

Fertilizer and tillage experiments which frequently are conducted in unduplicated plats should probably be at least triplicated. Reduction of error by replication is more effective than the use of check plats alone.

The introduction of check plats every fifth plat in itself occupies one-fifth of the land. The more refined methods of securing comparable stands of corn upon which to base the yields at harvest require much greater labor expenditure than formerly.

The proper conduct of experimental work in crop production in light of our present knowledge requires either a large extension in land area and labor facilities or else a marked restriction in the amount of investigation carried on.

MEASURING IMPROVEMENT IN YIELD THRU BREEDING

Comparing the yield of corn for one period of years with the yield of another period is an unreliable method for noting improvement thru corn breeding. An illustration of this method is found in a circular of the United States Department of Agriculture Office of Corn Investigations, August 20, 1914. The data in Table 34 were given in this circular as

TABLE 34—*Data given in Circular of Office of Corn Investigations, U. S. Department of Agriculture, August 20, 1914, to show improvement from ear-to-row breeding conducted at Piketon, Pike County, Ohio*

	Average for first seven years, 1901-1907 inclusive	Average for second seven years, 1907-1913 inclusive	Ratio first period to second period
	Bushels	*Bushels*	
Yield per acre as weighed in the fall (70 lbs. of ears to the bushel)....	77	85	100:110.4
Yield per acre of dry shelled grain (56 lbs. to the bushel)..........	63	75	100:119

indicating 19 per cent increase in yield of dry shelled corn per acre by ear-to-row breeding. The increase in yield of ear corn as weighed at husking time was 10.4 per cent. The measure of improvement by breeding was the average increased yield during a seven year period, 1907-1913, over the previous seven-year period.

A comparison of the yields in Table 35 during these same two periods for the state of Ohio as compiled from the United States Yearbook indicates a similar increase in yield for the state in general. During the last period of seven years, the Ohio state yield was 11.4 per cent higher than during the previous seven years. Likewise data compiled from the reports of the Ohio State Secretary of Agriculture, indicate 9.4 per cent greater yield for Pike County, in which the experiments were conducted, during the last seven years than during the previous seven years. This suggests that more favor-

TABLE 35—*Ohio state and Pike County yields of corn averaged for the same periods as given in Circular of the office of Corn Investigations, August 20, 1914*

	Average for first seven years, 1901-1907 inclusive	Average for second seven years, 1907-1913 inclusive	Ratio first period to second period	Average yield for nine years previous to first period
	Bushels	*Bushels*		*Bushels*
Yield per acre for state of Ohio as compiled from U. S. Yearbook......	34.4	38.3	100:111.4	32.8
Yield per acre for Pike County, Ohio, as compiled from the reports of the Ohio State Board of Agriculture.....	28.7	31.4	100:109.4	

able climatic conditions may have been the cause of the apparent improvement of the ear-to-row corn.

A similar method of measuring improvement by ear-to-row corn breeding at the Nebraska Experiment Station during the same period of 13 years, gives the results shown in Table 36. The yield of continuous ear-to-row breeding strains during the seven-year period 1907-1913 was 61 per cent as great as during the preceding seven years. It would appear that the corn yield had been reduced 39 per cent by ear-to-row breeding during the last seven years. However, a comparison of yields in Lancaster County, in which the Station is located, shows a decreased yield of 30 per cent, and the State as a whole a decreased yield of 17.3 per cent for the same two periods. Further, the yield of the original unselected Hogue's Yellow Dent corn showed a decreased yield of 35 per cent at the Experiment Station during the second seven-year period. All indications are that the reduced yield of ear-to-row corn at the Experiment Station was due to climatic conditions and not to the breeding. An actual comparison of the ear-to-row corn during the last period of seven years with the original corn of the same variety planted each year as a check indicates an actual increased yield of 5.4 per cent due to breeding, whereas the other method of comparison indicated a decreased yield of 39 per cent.

TABLE 36—*Nebraska data compiled to show results secured by the Nebraska Experiment Station from ear-to-row breeding if compared by the method of the Office of Corn Investigations reported in Table 31*

	Average yield for first seven years, 1901-1907 inclusive	Average yield for second seven years, 1907-1913 inclusive	Ratio	Average yield for nine years previous to first period
	Bushels	*Bushels*		*Bushels*
Yield for State of Nebraska as compiled from U. S. Yearbook	28.3	23.4	100:82.7	24.1
Average yield for Lancaster County	30.0	21.0	100:70	....
General crop of Hogue's Yellow Dent corn at the Nebraska Experiment Station	69.6	45.6	100:65.5	....
Yield per acre, at the Nebraska Experiment Station of Hogue's Yellow Dent corn which has undergone continuous ear-to-row breeding since 1902	81.5*	49.9	100:61.0	....
Yield per acre at the Nebraska Experiment Station of original unselected Hogue's Yellow Dent corn used as check for measuring improvement from breeding†	....	47.2	....	....

*The yield for ordinary Hogue's Yellow Dent Corn for 1901 is included in this average.

†Averaging together these data for the seven years 1909-1915—during which period the precaution was taken to have strictly comparable results by thinning to a uniform stand and to reduce error by several replications—we have an average yield for the continuous ear-to-row breeding stock of 49.2 bushels, and the comparable check yield is 48.9 bushels.

A comparison of the Hogue's Yellow Dent ear-to-row-selection with the original unselected Hogue's Yellow Dent corn for the seven-year period 1909-1915—during which time the precaution was taken to have strictly comparable results by thinning to a uniform stand, and to reduce error by several replications—indicates an increased yield of only six-tenths of one per cent due to the breeding.

In order to measure progress in the improvement of corn thru breeding, it is necessary to compare the results each year with the original unselected corn.

SOIL LIMITATION AS A SOURCE OF ERROR IN POT EXPERIMENTS

The past discussions in this bulletin have dealt entirely with field experiments. Extensive use has also been made of pots filled with soil for comparing the yields of various crops and soil types, and for determining the fertilizer needs of different soils and the water requirement of crops. A review of the literature indicates a marked lack of uniformity in the size of pots and rate of planting in them.

Tables 37 to 47 contain the results from experiments conducted during three years, 1913-1915, bearing upon the effect of the size and rate of planting as sources of experimental error in pot tests.

Galvanized iron pots were used, having a constant water supply from jars connected at the bottom. Rain was excluded by means of a closefitting cover about the stalk, and surface evaporation was reduced by means of a three-inch layer of gravel. All pots were planted each year from the same ear of Hogue's Yellow Dent corn. Suckers were removed as soon

TABLE 37—*Summary showing the effect of the size of the pot upon the growth of corn. Hogue's Yellow Dent corn (1913)*

Size of pot	Wt. of soil (moisture-free)	No. of pots averaged	Dry matter		Total leaf-area per plant	Height of stalk
			Ear	Total		
Inches	*Pounds*		*Grams*	*Grams*	*Sq. in.*	*Inches*
12x24...	86	4	28	165	680	71
16x36...	245	80	194	416	1070	89
30x36...	933	4	311	599	1440	83

as they started, so as to prevent variability in the number of stalks per pot. Thus uniform conditions were provided thruout all pots except the one or two variable factors under observation. The pots were located in trenches within a cornfield, with their tops level with the field. They were filled with fertile surface soil from the Experiment Station Farm. The manure which was used in half of the pots during 1914 and 1915, as designated, was well-rotted sheep manure, and was thoroly mixed with the upper ten inches of soil.

TABLE 38—*Summary of data showing the effect of the size of pot upon growth of corn. Hogue's Yellow Dent corn (1914)*

Size of pot	Moisture-free contents		No. of pots averaged	Dry matter		Total leaf-area per plant	Height of plant
	Soil	Manure		Ear	Total		
Inches	*Pounds*	*Pounds*		*Grams*	*Grams*	*Sq. in.*	*Inches*
12x12....	32.5		4	10	98	705	76
12x12....	32.5	1.75	4	82	269	1167	102
12x24....	85		4	63	206	1165	100
12x24....	85	1.75	4	186	402	1353	106
16x24....	150		4	108	316	1343	110
16x24....	150	1.75	4	270	535	1369	112
16x36....	239		3	242	442	1193	116
16x36....	239	1.75	8	287	558	1322	114
21x36....	583		4	299	628	1308	112
21x36....	583	1.75	4	341	708	1405	114
30x36....	956		3	405	728	1269	108
30x36....	956	1.75	4	416	781	1287	114

TABLE 39—*Showing in per cent the effect of increasing the size of pot. The results in the different sizes without manure are here expressed in per cent of the results in the smallest size without manure. Hogue's Yellow Dent corn (1914)**

Size of pot	Wt. of soil (moisture-free)	Dry matter		Total leaf-area per plant	Height of stalk
		Ear	Total		
Inches	*Pounds*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
12x12...........	32.5	100.0	100.0	100.0	100.0
12x24...........	85.0	632.5	211.0	165.2	131.3
16x24...........	150.0	1082.3	324.1	190.6	144.7
16x36...........	239.0	2417.0	453.6	169.3	153.0
21x36...........	583.0	2990.0	643.8	185.6	147.4
30x36...........	956.0	4046.7	747.0	180.0	142.1

*Data calculated from Table 38.

EFFECT OF THE SIZE OF POT UPON THE GROWTH OF CORN

In 1913 individual plants of Hogue's Yellow Dent corn were grown in pots of three different sizes. The results are summarized in Table 37. In pots containing 86, 245, and 933 pounds of soil, the average total dry matter harvested per pot was respectively 165, 416, and 599 grams, while the average weights of ear corn were 28, 194, and 311 grams.

In 1914, six sizes of pots were used, which contained 32, 85, 150, 239, 583, and 956 pounds of moisture-free soil. Four pots of each size were cropped without manure and four with manure. The results are summarized in Table 38. Table 39 shows in percentage the effect upon yields of increasing the pot size. Using the crop harvested in the smallest pots without manure as 100 per cent, the yields of total dry matter for the other sizes without manure were respectively 211, 324.1, 453.6, 643.8, and 747 per cent. The yields of ear corn were respectively 100, 632.5, 1082.3, 2417, 2990, and 4046.7 per cent.

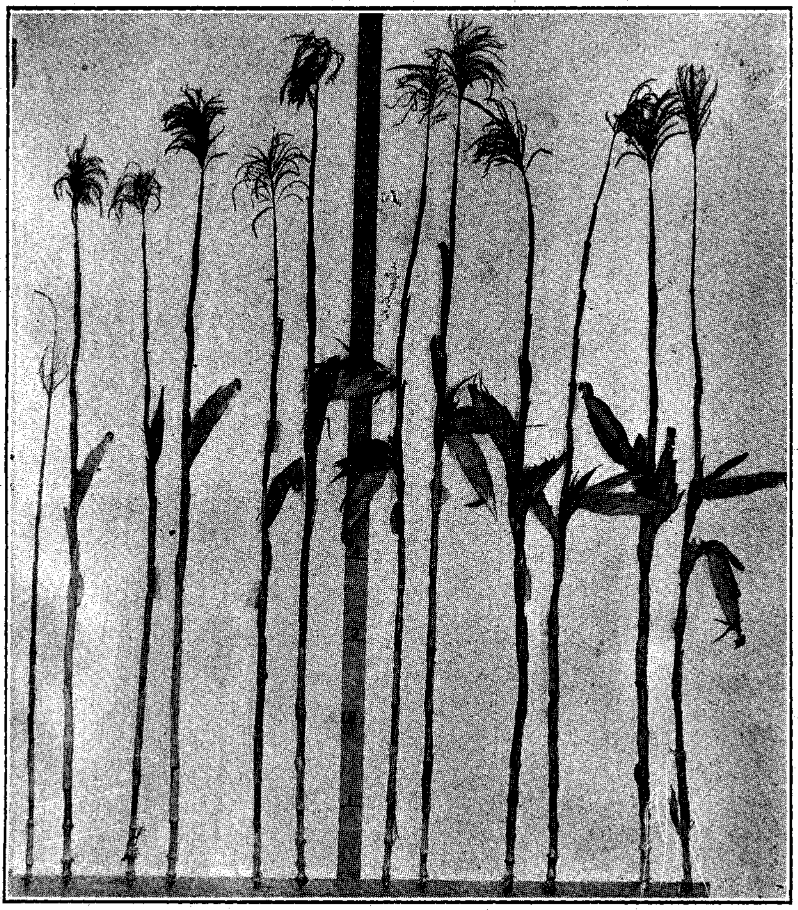
Table 40 shows in per cent the effect of applying a uniform rate of manure to the pots of different sizes in 1914. The yield with manure is expressed in per cent of the yield without manure for each size.

TABLE 40—*Showing in per cent the effect of applying a uniform rate of manure to pots of different sizes. The results with manure are here expressed in per cent of the results without manure. Hogue's Yellow Dent corn (1914)**

Size of pot	Wt. of soil (moisture-free)	Dry matter		Total leaf-area per plant	Height of stalk
		Ear	Total		
Inches	*Pounds*	*Per cent*	*Per cent*	*Per cent*	*Inches*
12x12	32.5	822.5	276.4	165.6	133.5
12x24	85.0	293.6	195.3	116.2	106.2
16x24	150.0	249 2	169 3	101.8	101.3
16x36	239.0	118.9	126.1	110.7	98.3
21x36	583.0	114.1	112.7	107.4	101.8
30x36	956.0	102.9	107.2	101.4	105.5

*Data calculated from Table 38.

Applying 1.75 pounds of moisture-free manure per pot increased the yields of total dry matter for the different sized pots respectively 176.4, 95.3, 69.3, 26.1, 12.7, and 7.2 per cent. Likewise, the manure increased the yields of grain per pot



1 2 3 4 5 6

Fig. 16—Representative plants of Hogue's Yellow Dent Corn grown one stalk per pot, in pots of different sizes, 1914. (Table 38) Each set contains a plant grown with and without manure. Pounds of soil per pot, left to right 1—32.5; 2—85; 3—150; 4—239; 5—583; 6—956

respectively 722.5, 193.6, 149.2, 18.9, 14.1, and 2.9 per cent, according to the size of the pot.

In the above experiment for 1914, the manure was applied on the individual plant basis. Assuming a normal stand of 3556 hills, each containing 3 plants, an acre of corn has 10,668 plants. One and seventy-five one hundredths pounds of moisture-free manure per plant would be at the rate of 9.33 tons per acre.

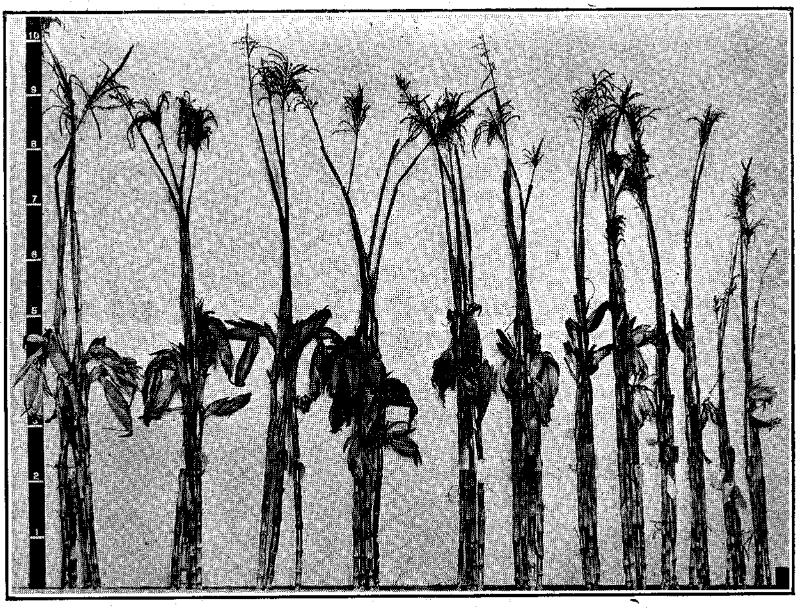
In 1915, the same six sizes of pots were used as in 1914, and contained respectively 36, 83, 161, 253, 561, and 920 pounds of moisture-free soil. There were eight pots of each size, four of which were manured. Table 41 contains a summary of the results. Table 42 shows in percentage the effect of increasing the pot size upon yield.

Based upon the yield in the smallest pots, without manure, the relative yields of dry matter for the respective sizes were 100, 150, 229.6, 355.6, 586, and 578.7 per cent. The relative yields of ear corn were respectively 100, 276.2, 819, 1,647.5, 2,771.3, and 2,667 per cent.

Table 43 shows in percentage the effects of applying, to the pots of different sizes, manure in amounts proportional

TABLE 41—*Summary of data showing the effect of the size of the pot upon the growth of corn. Hogue's Yellow Dent corn (1915)*

Size of pot	Moisture-free contents		No. of pots averaged	Dry matter		Total leaf-area per plant	Height of plant
	Soil	Manure		Ear	Total		
Inches	*Pounds*	*Pounds*		*Grams*	*Grams*	*Sq. in.*	*Inches*
12x12....	36		4	10.5	108	753	71
12x12....	36	.08	4	17.8	107	776	80
12x24....	83		4	29	162	1061	98
12x24....	83	.18	4	30	172	1219	102
16x24....	161		4	86	248	1150	109
16x24....	161	.36	4	76	273	1238	111
16x36....	253		4	173	384	1209	114
16x36....	253	.55	4	203	456	1266	111
24x36....	561		3	291	633	1323	120
24x36....	561	1.25	4	366	684	1372	116
30x36....	920		4	280	625	1226	116
30x36....	920	2.00	4	331	685	1307	112



1 2 3 4 5 6 7 8 9 10 1

Fig. 17—Crop harvested from pots of six different sizes, 1915 (Table 41). One plant was grown per pot, with four pots of each size. Odd numbers without manure, even numbers with manure. (Manure added in proportion to soil contents.)

Pounds of soil, left to right: 1 and 2—920 lbs.; 3 and 4—561 lbs.; 5 and 6—253 lbs.; 7 and 8—161 lbs.; 9 and 10—83 lbs.; 11 and 12—36 lbs.

to the amount of soil. Two pounds of moisture-free manure were applied to the largest pots, while the amounts added to the other sizes were respectively 1.25, 0.55, 0.36, 0.18, 0.8 pounds. Expressed in per cent of the yields without manure, the manured pots yielded 99.1, 106.2, 110.1, 118.8, 108, and 109.6 per cent total dry matter, and 169.5, 103.5, 88.4, 117.3, 125.7 and 118.2 per cent of ear corn.

TABLE 42—*Showing in per cent the effect of increasing the size of the pot. The results in the different sized pots without manure are here expressed in per cent of the results in the smallest pots without manure. Hogue's Yellow Dent corn (1915)**

Size of pot	Wt. of soil (moisture-free)	Dry matter		Total leaf-area per plant	Height of stalk
		Ear	Total		
Inches	*Pounds*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
12x12	36	100.0	100.0	100.0	100.0
12x24	83	276.2	150.0	140.9	138.0
16x24	161	819.0	229.6	152.7	153.5
16x36	253	1647.5	355.6	160.6	160.6
21x36	561	2771.3	586.1	175.7	169.0
30x36	920	2667.0	578.7	162.8	163.4

*Data calculated from Table 41.

TABLE 43—*Summary of data showing the effect of applying manure proportional to the amount of soil in pots of different sizes. The results with manure are here expressed in per cent of the results without manure. Hogue's Yellow Dent corn (1915)**

Size of pot	Wt. of soil (moisture-free)	Dry matter		Total leaf-area per plant	Height of stalk
		Ear	Total		
Inches	*Pounds*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
12x12	36	169.5	99.1	103.1	112.7
12x24	83	103.5	106.2	114.9	104.1
16x24	161	88.4	110.1	107.7	101.8
16x36	253	117.3	118.8	104.7	97.4
24x36	561	125.7	108.0	103.7	96.6
30x36	920	118.2	109.6	106.6	96.6

*Data calculated from Table 41.

EFFECT OF PLANTING AT DIFFERENT RATES UPON THE GROWTH OF CORN IN POTS

In 1915, corn was planted at four different rates, namely one, two, four, and six plants in pots 16 by 36 inches in size and containing 253 pounds of soil. The results are contained in Tables 44, 45, and 46. Without manure (Table 45) the individual plants in the six, four and two-rate yielded respec-

TABLE 44—*Summary of data showing the effect of different rates of planting upon growth of corn in pots. Hogue's Yellow Dent corn (1915)*

Rates of planting per pot	Moisture-free contents		No. pots averaged	Dry matter*		Total leaf-area per plant†	Height of stalk
	Soil	Manure		Ear	Total		
	Pounds	*Pounds*		*Grams*	*Grams*	*Sq. in.*	*Inches*
1	253		4	232	476	1334	123
1	253	1.55	8	262	539	1457	115
2	253		4	92	242	1210	120
2	253	1.55	4	118	279	1153	112
4	253		4	37	127	895	106
4	253	1.55	4	37	151	990	105
6	253		4	6.5	79.0	714	90
6	253	1.55	4	16.7	101.9	861	93

*Where more than one plant was grown in a pot, the average yield per plant is given.

†The leaf-area is not very significant inasmuch as the lower leaves died prematurely according to the rate of planting—due to malnutrition.

TABLE 45—*Summary of data showing the effect of different rates of planting upon growth of corn in pots. The results at different rates of planting without manure are here expressed in per cent of the results from one plant per pot. Hogue's Yellow Dent corn (1915)**

Rate of planting per pot	Wt. of soil (moisture-free)	No. of pots averaged	Dsy matter per plant		Total leaf-area per plant	Height of stalk
			Ear	Total		
	Pounds		*Per cent*	*Per cent*	*Per cent*	*Per cent*
1	253	4	100	100	100	100
2	253	4	39.7	50.8	90.7	97.5
4	253	4	15.9	26.7	67.1	86.2
6	253	4	2.8	16.6	53.5	73.2

*Data calculated from Table 44.

Fig. 18—Normal plants of Hogue's Yellow Dent corn, grown one plant per pot, 1915

Fig. 19—Plants in the foreground grown six, four and two plants per pot

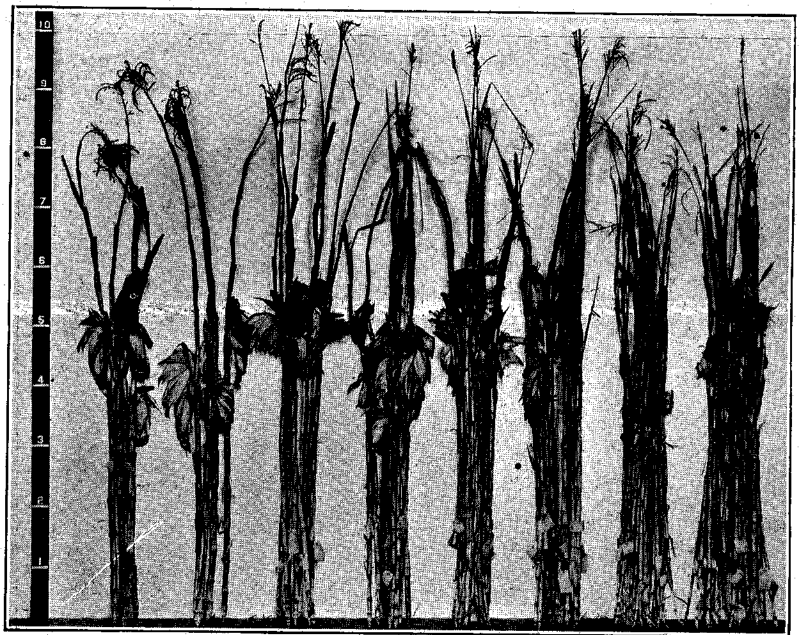


Fig. 20—Crop harvested from four pots planted at each of the following rates per pot. Left to right, 1 and 2, one plant per pot; 3 and 4, two plants per pot; 5 and 6, four plants per pot; 7 and 8, six plants per pot. Odd numbers without manure, even numbers with manure. (Table 44.) 1914

tively 16.6, 26.7, and 50.8 per cent as much total dry matter as the one-rate, and their yield of ear corn was respectively 2.8, 15.9, and 39.7 per cent as much per plant.

An application of 1.55 pounds of manure per pot (Table 46) increased the yields of total dry matter for the one, two, four and six-rates respectively 13.2, 15.3, 18.9, and 29.0 per cent. The yields of ear corn were 112.9, 128.3, 100.0, and 257.0 per cent as large with manure as without manure in the one, two, four, and six-rates respectively.

TABLE 46—*Summary of data showing the effect of different rates of planting upon growth of corn in pots. The results at the different rates of planting with manure are here expressed in per cent of the results without manure. Hogue's Yellow Dent corn (1915)**

Rate of planting per pot	Wt. moisture-free contents		No. of pots averaged	Dry matter per plant		Total leaf-area per plant	Height of stalk
	Soil	Manure		Ear	Total		
	Pounds	*Pounds*		*Per cent*	*Per cent*	*Per cent*	*Per cent*
1	253	1.55	8	112.9	113.2	109.2	93.5
2	253	1.55	4	128.3	115.3	95.3	93.3
4	253	1.55	4	100.0	118.9	110.6	99.1
6	253	1.55	4	257.0	129.0	120.6	103.3

*Data calculated from Table 44.

STATEMENT OF METHODS IN BULLETINS

A knowledge of the methods employed in crop testing is vital for intelligently evaluating the published results. Without a statement of methods, the reader is obliged to assume that reliable methods were employed. Such an assumption is not warranted, since many methods used are known to be faulty. Not only the experiment station worker but the farmer as well should be given an opportunity to know in detail how the tests were made. Increased experimentation by farmers has led many of them to be interested in methods.

The following brief summary table indicates the extent to which experiment station bulletins dealing with crop tests and published in the United States during the years 1900-1914 report details as to methods. A mere statement of results is incomplete and does not carry conviction.

TABLE 47—*Extent to which experiment station bulletins report the methods of investigation*

Method details	Per cent bulletins* reporting method details for			
	Variety tests	Fertilizer tests	Cultural tests	Pot tests
	Per cent	*Per cent*	*Per cent*	*Per cent*
Years' duration of tests	71	25	3	55
Size of plats	29	21	2	
Shape of plats	23	8	1	
Number of duplicates averaged	13	3	1	25
Distribution of duplicates	8	3		10
Use of check plats	8	11	1	20
Number of check plats	5	14	1	20
Distribution of check plats	3	5		5
Uniformity of conditions	41	21	2	40
Size of pots				55
Capacity of pots				45
Maturity of crop in pots				45

*The total number of bulletins reviewed were: variety tests, 253; fertilizer tests, 146; cultural tests, 52; pot tests, 20.

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